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INTRODUCTION

By W. T. SEDGWICK, Director

THE present volume is the fifth in a series of reprints of similar character, viz., of papers concerning various aspects of sanitary science, and connected more or less closely with public health problems arising from time to time in the regular work of a great modern school of science and technology. This volume, too, like those that have preceded it, owes its existence chiefly to the continued interest and the generous coöperation of an anonymous friend of the Institute, who, feeling keenly the incongruity of a twentieth century civilization which boasts of its achievements in mechanical, industrial, and chemical science and yet values human life so meanly as to go on polluting rivers and harbors with vast and ever increasing streams of putrefying sewage, is anxious to bring about a change for the better. Happily, signs are not wanting that many others, also, are today beginning to be conscious of the same incongruity, for the previous volumes of this series are already long since out of print, owing to an eager demand for them which has been as gratifying as it was unexpected.

Reforms, of whatever sort, are seldom without their drawbacks, and experience is showing that the water-carriage system of sewerage, while on the whole, for the use of thickly settled communities, an immense improvement upon all previous systems, brings with it certain serious disadvantages. Of these one is that, by enormously diluting with water the dangerous wastes of human and animal life, it vastly increases volume, and for this reason, and also because water is an excellent solvent as well as extremely penetrating, the mixture mingles readily with most materials so that wide dispersion of the wastes in the environment is favored and facilitated. Another disadvantage of the water-carriage system is that on sufficient dilution the objectionable and characteristic appearances and odors, which serve as useful warnings of the presence of these dangerous wastes, diminish or even disappear, although such diminution or disappearance does not generally mean that they are destroyed, but perhaps only more widely separated or dispersed. Still another disadvantage is that the water-carriage system removes rapidly and often to a considerable distance the fluid filth of a community, so that, while accomplishing quite perfectly a most desirable riddance, the very perfection of the system puts the sewage out of sight and out of smell, and hence too often out of mind, of those responsible alike for its production and for its ultimate sanitary disposal. As a corollary of these consequences of modern systems of sewerage, local nuisances, and dangers formerly domestic and almost intolerable have, indeed, been removed to a distance, or even done away, but often only at the cost of their conversion into more widespread, though often invisible, dangers. The most hopeful sign of progress in the subject of sewerage and sewage disposal is the growing sensitiveness of the public to this fact, for it is obviously bad citizenship for any one to clean up at the expense of others, and no more so for an individual or a family than for a community of individuals or families. The pouring of fluid filth into our rivers, lakes, and harbors does, of course, rid our cities, towns, and villages of that filth, and in so far it is commendable. But if by this act we simply move that filth to a distance, there to make for ourselves or for others more or less of the same trouble which it formerly made for us, then we are hardly superior in sanitation to those half-nomads who encamp on one spot until they have made sanitary conditions intolerable, and then remove their abode to a fresh location.

Most of the papers in this volume deal with various aspects of the endeavor—now almost world-wide—to purify that fluid filth which we call sewage, so that it shall not merely be turned as it comes into streams, lakes, or the sea, there to cause pollution, putrefaction, or possibly disease, but shall first be worked over in some way and made unobjectionable to the eye and the nose, and innocuous to life and health.

Professor Phelps's paper on the pollution of streams by the wastes of mills making wood-pulp by the sulphite process is a courageous attempt to grapple with a very difficult and growing problem, while another paper from his pen, on the disinfection of sewage, is a valuable continuation of his earlier and epoch-making work on that timely and interesting subject. If by disinfection of sewage or water the danger of their transportation of specific disease germs can be eliminated, and if by any process whatsoever the danger of putrefaction, present and future, can be overcome, then, as will follow from what has been said above, the objectionable and dangerous features of the fluid filth of communities will largely disappear.

The paper by Professor Winslow on the sanitary significance of bacteria in the air of sewers and other drains is noteworthy for two reasons. First, because it serves to establish by the only certain method known to science—the method of experiment—a harmony such as ought to exist always between the results of experiment and the results of experience. This paper deals, as its title hardly suggests, with the long popular theory of sewer gas and its dangers—a theory which, after having enjoyed an immense vogue, rapidly declined in importance during and after the decade of the great pathological discoveries (1876–86) and the establishment of the parasitic theory of infectious disease. Recently, however, it has been revived and strengthened by experimental evidence obtained by a distinguished English investigator. It therefore became imperative to reëxamine it and to confirm if possible the new evidence. This task Professor Winslow has patiently and skillfully undertaken, with the results stated in his paper.

In the second place, this piece of work deserves special attention because it was carried out largely by funds contributed for the purpose by a committee—the Sanitary Committee—of the Master Plumbers' Association of the United States. This committee, of which Mr. David Craig, a practical plumber of Boston, was chairman, desired to do something by scientific research to increase the knowledge available for the practical purposes of the plumbing trade. The chairman accordingly applied to the director of the Sanitary Research Laboratories and Sewage Experiment Station for advice concerning the status of the sewer gas problem and its real importance. He was eventually referred to Professor Winslow as one competent to give further advice and to make all necessary investigations, and the paper here reprinted is the practical outcome of Mr. Craig's and Professor Winslow's plan of attack. It is impossible not to admire the wisdom, the liberality, and the public spirit of the leaders of a modern trade which thus, like the guilds of the Middle Ages, seeks earnestly, intelligently, and scientifically to make more secure those principles which shall serve as safe guides in practice.

The Staff of the Laboratory and Station remains, happily, almost unchanged, so that a continuous plan of work has been followed out from the beginning. The principal workers and designers of work have been, as hitherto, Professor C.-E. A. Winslow, Biologist in Charge, and Professor Earle B. Phelps, Research Chemist and Bacteriologist.

It is, however, to the anonymous Donor, whose keen and stimulating suggestions and criticisms and whose substantial support have given both life and power to the work, that public thanks are primarily due for the results attained.

The Sanitary Significance of Bacteria in the Air of Drains and Sewers

By C.-E. A. WINSLOW

Biologist-in-charge of the Sanitary Research Laboratory and Sewage Experiment Station of The Massachusetts Institute of Technology

REPORT MADE TO THE SANITARY COMMITTEE OF THE NATIONAL ASSOCIATION OF MASTER PLUMBERS OF THE UNITED STATES, AND REPRINTED FROM THE REPORT OF THE SANITARY COMMITTEE FOR 1907-1908-1909

BOSTON, MASS, 1909

THE SANITARY SIGNIFICANCE OF BACTERIA IN THE AIR OF DRAINS AND SEWERS.

C.-E. A. Winslow
Biologist-in-charge of the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology

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I. HISTORY AND PRESENT STATUS OF THE PROBLEM.

In 1858, when the causes of epidemic disease were still shrouded in profound mystery, an able and distinguished sanitarian, Charles Murchison, brought forward what he held to be conclusive evidence that typhoid fever was "produced by emanations from decaying organic matter." To disease thus generated spontaneously from decomposing filth he gave the name "pythogenic" from two Greek words meaning "generated by decay." For a long time this theory of disease held complete sway, particularly in England. It was energetically applied by Chadwick and others to the practical reform of existing conditions and produced a far-reaching improvement in the cleanliness of cities and towns, not only in England, but in every other civilized country. In particular the substitution of house drainage and municipal sewerage systems for privy vaults and cesspools made rapid progress to the notable advancement of the public health.

It was not unnatural that the horror of filth inculcated by these early sanitarians should have developed into an equally extreme dread of the systems of pipes and drains by which the filth was carried away. Sewer gas became the residuary legatee of the whole pythogenic theory. Even twenty-five years ago it was conceived as a deadly miasma laden with the elements of almost every disease known to medical science. One prominent writer of the time said, "If we look for the cause of the large mortality from zymotic diseases in our cities, we find it principally in sewer-gas poisoning. Other causes operate to swell the total, but to bad plumbing we may attribute the prevalence of pythogenic pneumonia, peritonitis, inflammatory rheumatism, typhoid and malarial fevers, croup, diphtheria, and many kindred diseases." This is scarcely an extreme statement of the best sanitary opinion of a generation ago.

When the germ theory of disease was established between 1860 and 1880, by the work of Pasteur and Koch, it was necessary to revise these earlier views. It was proved by Pasteur and his successors that epidemic diseases are caused not by gaseous emanations but by minute plant and animal parasites and that these parasites are not generated in decomposing filth but come from previous cases of disease. It was easy to see how filthy conditions, which lead to the contamination of food by excreta, promote the spread of germs. It did not follow, however that the air of drains and sewers could spread the living microbes of disease, without the direct contact of some more tangible carrying agent. This point remained to be proved; and a new field of experimental bacteriology had to be developed before the question could be answered. Nägeli was, perhaps, the first to study this point carefully. In his book *Die niederen Pilze,* (Munich, 1877), he reported numerous experiments bearing on the transmission of germs from liquids into the adjacent air. Putrescent and putrescible liquids were kept in sealed vessels together for over three years without air infection taking place; in another series of experiments air was drawn through a layer of sand, wetted with a putrescing liquid, and then through a sterile infusion, without infecting the latter. Nägeli concluded that "Infectious materials in general, pass into the air only after drying, and then in the form of dust."

If this conclusion were justified there seemed little danger of the carriage of bacteria by the constantly saturated air of sewers. A new possibility was suggested at about this time, however, by some experiments of Sir Edward Frankland in England on the discharge of chemicals in solution into the air under various conditions. He used a solution of lithium chlorid and tested for its presence by exposing the air above to the action of a Bunsen burner. After violent agitation with a wooden rod no lithium could be detected in the air. When, on the other hand, effervescence was produced in the solution by the addition of hydrochloric acid and marble, the characteristic color of lithium was apparent in the Bunsen flame at the end of a tube 21 feet above the liquid. The conclusions were drawn that "the moderate agitation of a liquid does not cause the suspension of liquid particles capable of transport by the circumambient air," but "the breaking of minute gas bubbles on the surface of a liquid consequent upon the generation of gas within the body of the liquid is a potent cause of the suspension of transportable liquid particles in the surrounding air; and therefore when, through the stagnation of sewage or constructive defects which allow of the retention of excrementitious matters for several days in the sewer, putrefaction sets in and causes the generation of gases, the suspension of zymotic matters in the air of the sewer is extremely likely to occur." (E. Frankland, On the Transport of Solid and Liquid Particles in Sewer Gases; Proceedings of the Royal Society of London, 1876—7, XXV., 542.)

Almost exactly similar results, as regards bacteria, were reported in this country by Raphael Pumpelly in a communication to the National Board of Health on The Relation of Soils to Health, (Annual Report of the National Board of Health for 1881, p. 223). He drew air over a decomposing liquid and then bubbled it through a sterile putrescible fluid; or else bubbled it through the two liquids in succession. His final conclusions were as follows: "At normal summer temperatures no germs were given off from the decomposing liquids whenever their surfaces remained unbroken, even though in some of the experiments the air was continuously conducted over them in a slow current. When the surfaces of the liquids were broken, however, by the bursting of bubbles, germs were invariably given off and the sterilized infusions infected, no matter how slowly the aspiration was conducted."

These investigations clearly indicated that bacteria could be given off to the air from an infected liquid by the bursting of bubbles. It was important to determine by an examination of the actual conditions in drains and sewers how serious this contamination might be; and in the eighties, when bacteriology was a fascinating novelty, there were many investigators ready to attempt the task.

Some of the earliest bacterial examinations of sewer air were made by the French bacteriologist, Miquel, and reported in his work on the living organisms of the air, (P. Miquel, Les organismes vivants de l'atmosphere, Paris, 1883). He discussed his results as follows: "In summer the air of the Rue de Rivoli may be five or six times as impure as the air of the sewer. In winter the reverse relation may be found; the air of the public street may be five or six times as pure as the air of the sewer below." Miquel found that the germs isolated from sewer air were of somewhat different character from those observed in the atmosphere of the street. They grew more rapidly in his flasks, more frequently produced putrefactive changes and more often grew under anaerobic conditions. Inoculation into animals, however, failed to reveal the presence of any pathogenic forms.

At a later date, in 1893, Miquel began to make routine monthly examinations of the air of the Paris sewers in connection with the work of the Montsouris observatory. From that year until 1899 he published annually a table, showing, by months, the relative number of bacteria in the air of a Paris street, (Hotel de Ville), and in the Paris sewers, in comparison with the number present in the air of the country at Montsouris, (Annuaire statistique de la ville de Paris). The yearly averages for the three locations are shown in the table below.

BACTERIA IN COUNTRY AIR, CITY AIR AND SEWER AIR

(Miquel). Bacteria per cubic meter.

Year	Country Air Montsouris	City Street Hotel de Ville	Sewer Air
1893	285	8435	5015
1894	230	9775	2920
1895	330	7615	2590
1896	—	6205	3965
1897	197	5410	3875
1898	—	5200	2075
1899	—	6595	2910

Uffelmann in 1886-7, (Uffelmann, Luftuntersuchungen, ausegeführt im hygienischen Institut der Universität Rostock, Archiv fur Hygiene, 1888, VIII., 262), examined the air of the main drain of a house at Rostock just above what corresponded to the running trap, taking 9 samples at intervals extending over a year. The largest number of bacteria found in 10 liters of air was 8, the smallest 0, and the average, 3. *Aurococcus aureus*, (*Staphylococcus pyogenes aureus*), was isolated twice, but no other pathogenic organisms were found.

In 1887, Petri examined the air of a Berlin sewer and found on one occasion 1 bacterium and 3 molds in 100 liters of air; on another occasion no bacteria and one mold in the same volume, (R. J. Petri, Eine neue Methode Bacterien und Pilzsporen in der Luft nachzuweisen und zu zählen, Zeitschrift fur Hygiene, 1888, III., 1).

One of the most important studies of the actual condition of sewer air was carried out in England in this same year (1887) by Carnelley and Haldane (T. Carnelley and J. S. Haldane. The Air of Sewers, Proceedings of the Royal Society of London, 1887, XLII., 394 and 501). These investigators examined the sewers under the Houses of Parliament at Westminster, and also a number of sewers in Dundee, using Hesse's sedimentation tube method for their quantitative work. In each case their results were controlled by the examination of the air of adjacent streets. It appeared that in almost every case the number of micro-organisms present was smaller in the sewers than in the streets. The average for the whole series gave about 9 per liter in the former and 16 per liter in the latter. Furthermore the number of micro-organisms present was highest in the best ventilated sewers and varied with variations in the contents of the street air. The kinds of colonies appearing on the plates and the proportion of molds to bacteria was the same in street and sewer air. The authors concluded that "The micro-organisms in sewer air come entirely, or nearly so, from the outside and are not derived, or only in relatively small numbers, from the sewer itself." They note, however, one interesting exception. In several cases drains entering the sewers from above discharged their contents so as to produce a violent splashing. Under such circumstances a considerable increase in the bacterial content of the air was apparent in the vicinity.

The points of greatest significance in this work appear to be two; first, that air in contact with a stream of quietly flowing, infected liquid contains less bacteria, rather than more, on account of the proximity of the wet surface; and second, that the splashing of such a liquid may cause at least a transitory infection of the adjacent air. Both these facts were also demonstrated by Carnelley and Haldane experimentally in the laboratory. They drew the air of the room through a glass tube 5 feet long, in which a stream of water was flowing,—the velocity of the air current being 10 inches per second. The number of bacteria in the air decreased by nearly half. On the other hand air drawn through a box into which an infected liquid was splashed from a height showed an infection of 300—600 bacteria per liter even after passage through the 5-foot glass tube.

The final conclusions of the authors were as follows, "The results of the foregoing investigations are clearly such as to make us much more suspicious as to supposed evidence of the bad effects of ordinary sewer air, such as that of the sewers examined by us. At any rate it is evident that 'sewer gas,' unless it has been vitiated by splashing, has a much less deadly composition than is often supposed."

Essentially the same experiments were presented by Dr. Haldane at the Bolton Congress of the Sanitary Institute. (J. S. Haldane, The Air of Buildings and Sewers; Transactions of the Sanitary Institute of Great Britain, 1887-8, IX., 395); but he also reported some additional examinations made in the sewers of Bristol which were selected from the fact that they were entirely closed except at two manholes near the outfall. At one manhole in which a current of air was setting out from the sewer only 2 micro-organisms per liter were found. At the other manhole there was a down current which mixed street and sewer air. The number of organisms here was about 8 per liter against 13 for the air of the street.

Similar results were reported a little later by Robertson, (A Study of the Micro-organisms in Air, especially those in Sewer Air, and a New Method of Demonstrating them; British Medical Journal, 1888, Dec. 15). He found less bacteria in the air of the sewers of Penrith, than in street air; the average numbers per liter were 4 and 6 respectively. More bacilli were found in the sewer air and more cocci in the street air.

A few years later, two important reports upon this subject were made to the London County Council by Laws, (J. P. Laws, Report on Sewer Air Investigations, London County Council No. 126, 1893), and J. P. Laws and F. W. Andrewes, Report on the Result of Investigations on the Micro-Organisms of Sewage. London Council No. 216, 1894). In the first of these papers Mr. Laws reported from an examination of London sewers that, "Sewer air contains a smaller number of bacteria than outside air," and that, "the micro-organisms in the sewer air are related to the micro-organisms in the air outside, and not to the micro-organisms of the sewage." From a series of experiments carried out in an experimental 9 foot sewer, 80 feet long, he concluded that the wetted surfaces of a sewer cannot give off germs to the air under natural conditions. He kept the sewer full for several periods of 24 hours, partially emptied it, and drew air through it, even at rates as high as 5 and 15 feet per second, without finding evidence that bacteria had been detached from the walls. Even splashing he concluded was unlikely to produce appreciable infection. Sewage falling into an egg-shaped sewer, 11 feet by 9, from the middle of its height produced practically no effect upon the number of micro-organisms in the air.

In a second investigation, in collaboration with Dr. Andrewes, Mr. Laws extended his work by a careful comparison of the kinds of bacteria found in sewage and sewer air. The most abundant forms in the sewer air were molds and micrococci, which are characteristic of ordinary street air and are rare in sewage. On the other hand, *B. coli* the most typical sewage form, was never found in sewer air. The authors conclude as follows, "We consider, therefore, that the study of the sewage bacteria, on which we have been engaged, fully confirms the conclusion previously arrived at from the study of the micro-organisms of sewer air, viz., that there is no relationship between the organisms of sewer air and sewage."

At about the same time Smith, (J. McG. Smith, Air in the Sewers of Sydney, Sixth Annual Report of the Metropolitan Board of Water Supply and Sewerage, 1893), reported rather high numbers of bacteria in the air of the sewers of Sydney. As an average of 20 determinations he found 225 germs per liter, the individual numbers ranging from 7 to 2260. The particular forms listed by him were almost without exception organisms common in street air.

A year later, in 1894, Dr. A. C. Abbott of Philadelphia reported an interesting series of experimental studies along the line of the earlier work of Nägeli and Pumpelly. (Chemical Physical and Bacteriological Studies upon Air over Decomposing Substances with special reference to their Application to the Air of Sewers; Transactions of the Congress of American Physicians and Surgeons, Third Triennial Session, p. 28). When air was bubbled through an infected liquid and then drawn through a tube of 15 mm. inside diameter and 1 meter long bacteria were transported by a current, having a velocity of 16.5 cm. per minute, but not by a current of 8.6 cm. per minute or less. With a tube 4.5 meters long a velocity of 268 cm. per minute carried bacteria in only two out of four experiments. In a second series of investigations Petri dishes were exposed in a large bell jar around an open dish of a culture of *B. prodigiosus.* Bubbling of the culture was brought about, either by adding to it a solution of dextrose and a culture of yeast, or by blowing air into it through a tube passed through the side of the bell jar. When the culture was agitated by natural fermentation no colonies of *B. prodigiosus* appeared on seven plates after three days. With artificial bubbling at a low velocity, (3 1-2 liters in 6 hours), 12-38 colonies appeared on the plates after twelve hours. Dr. Abbott concluded that the danger of bacteria being transmitted under natural conditions was practically negligible.

There was an important discussion of the sewer gas problem at the meeting of the German Society of Public Health at Stuttgart in 1895. Dr. Kirchner of Hanover, and City Engineer Lindley of Frankfurt presented the chief paper of the session, (M. Kirchner and Lindley, Schädlichkeit der Canalgase und Sicherung unserer Wohnräume gegen dieselben, Deutsche Vierteljahrsschrift fur offentliche Gesundheitspflege, 1896, XXVIII., 152). No new experimental data were offered but the evidence at hand, bacteriological and epidemiological, was reviewed, and the following principal conclusions were reached:

1. The assumption of the spread of epidemic diseases, such as Typhoid, Cholera and Diphtheria, by sewer gas does not harmonize with our present knowledge of the nature of the causative agents of these diseases.

2. On the other hand, the gaseous products of decomposition arising in sewers and house-drains may be harmful, indirectly if not directly, to those exposed to them for a considerable time; they may produce nausea and may lower the general tone of the body, including its resistance against disease." In the succeeding discussion which was participated in by a number of the leading sanitarians of Germany, similar opinions were expressed by many, although the conclusions of the authors which were presented in the form of resolutions, were not adopted by the Congress. In the discussion of Kirchner and Lindley's paper, (Deutsche Vierteljahrsschrift fur offentliche Gesundheitspflege, 1896, XXVIII., 196), Ficker stated that in experiments made at the Hygienic Institute of Breslau it appeared that air currents of a velocity of several meters per second would not lift specific germs from half-moist soil or from various surfaces on which they had been dried. On the other hand, the same observer found that when an infected liquid was discharged in a fine spray into a tube, an air current of .5 cm. per second could transport germs to a vertical distance of seven meters.

No further experimental results on the bacteriology of sewer air appear to have been reported, from 1896 to 1907. Public opinion among hygienists molded itself upon the data accumulated in the eighties and early nineties. The interpretation placed upon these data has, however, varied curiously in different countries, and has given rise to that anomalous, but not unprecedented phenomenon, a national difference in scientific opinion.

In Germany the obvious practical difficulty in conceiving of the transfer of infectious germs by the agency of moist air, and the experimental results of Nägeli, Miquel, Petri, Uffelmann, Carnelley and Haldane and Laws and Andrewes, have led to an almost universal scepticism

Prof. Flügge of Breslau, as far back as 1889, (Grundriss der Hygiene), said, "Still less are the gaseous products of fecal decomposition in position to carry infection. The special danger from fecal matter has been erroneously held to lie in these emanations. Malodorous gases from closets or sewers have been held responsible by physicians and laymen alike, particularly in England, for the spread of typhoid, diphtheria, erysipelas, puerperal fever, etc.; but this attitude is entirely uncritical and ignores the most recent results of investigation. The untenability of such views has been clearly shown above." In one of the most important German treatises on hygiene, Büsing (Die Kanalisation Weyl's Handbuch der Hygiene, Band II), says, "Whether besides the poisonous gases in sewer air, the micro-organisms present have any appreciable significance, is doubtful. Miquel has made studies of the occurrence of bacteria in the air of some Paris sewers with good currents which showed that their number was small, smaller than the number found in the air of hospitals, and much smaller than the number found in the air of streets in which there was considerable traffic."

These quotations are typical of German expert opinion in regard to the transmission of bacteria by sewer air; and in this country the best sanitary authorities have reached identical conclusions.

Dr. Charles Harrington, perhaps the leading medical sanitarian in this country, said, "The majority and the best of German investigators, as Flügge, Rubner, Gärtner, Soyka, Prausnitz and others, maintain that sewer air and sewer gases are quite incapable of conveying the germs of typhoid fever and other infective diseases. It is true that some of the gases given off in the putrefaction processes which go in sewers are more or less poisonous, but whether they are capable of producing any injurious effects depends very much on the amount inhaled and on the degree of concentration. In any event, they are certainly incapable of producing any infective disease in the absence of the specific germ," (C. Harrington, A Manual of Practical Hygiene, Philadelphia and New York, 1901).

In the engineering branch of the profession the same opinion prevails. Considerable attention has been directed to the question during recent years in the city of Winnipeg, Manitoba, on account of an undue prevalence of typhoid fever. This was attributed in public discussion to the foul air arising from sewer inlets and ventilating manholes. After a careful study by Col. H. N. Ruttan, the City Engineer, and by Allen Hazen, Consulting Engineer, of New York, Mr. Hazen reported that Col. Ruttan has "investigated the plumbing in a considerable series of houses in Winnipeg with the general result of finding that the plumbing is not associated with typhoid fever. In fact, his statistics show a somewhat larger proportion of cases of typhoid fever in the houses where the plumbing is good, than in those where it is defective." Mr. Hazen sums up the best current American opinion in the following sentence: "After many years of experience and long-continued investigation there is not the slightest reason to believe that infectious diseases are carried by the air of sewers," (Engineering News, LIII., 246). So Whipple, in the latest American text-book on typhoid fever, (G. C. Whipple, Typhoid Fever, New York, 1908), says, "Typhoid germs do not readily leave a moist surface. Sticky by nature, they adhere until dessication loosens their dead cells. For this reason, sewer air is not to be looked upon as a direct means of infection."

In England, on the other hand, a widely different attitude toward the sewer gas question has been maintained. The old pythogenic theory has kept a strong hold on the minds of the conservative British sanitarian; and the numerous cases where typhoid fever and other diseases have been attributed to sewer gas by attending physicians and health officers have outweighed scientific experimental evidence.

In Notter and Firth's Standard Hygiene the authors say of sewer air, "Fungi and bacteria grow rapidly in such air, and meat and milk soon taint when exposed to it. We must also suppose, for facts leave us no other explanation, that those agencies which produce enteric fever may also be present. That dysentery and diarrhoea may also be caused by exhalations proceeding from a foul sewer we cannot doubt but the precise agency is here also unknown. Diphtheria and acute follicular tonsilitis are also associated with sewer air; and, if the disease does not originate *de novo,* when once it breaks out, its tendency is to spread where the air and soil are polluted by sewage," (J. L. Notter and W. H. Horrocks, The Theory and Practice of Hygiene, London, 1900).

To quote an engineer, Maguire, in his lectures on Domestic Sanitary Drainage and Plumbing, (London, 1901), says, "It is almost a settled question that the germs of typhoid fever, cholera, dysentery, diarrhoea and other diseases may be present in and spread by cesspool and sewer air. Small-pox, scarlatina, measles, etc., if not arising directly from sewer air, may be communicated from house to house by unsuspected sewer and drain connections of one or more houses with an infected house on the same line of public sewer." Middleton, writing from the standpoint of the architect (The Drainage of Town and Country Houses, London, 1903), states that the "principal disadvantage," of the water-carriage system of sewage "lies in the possible generation of sewer gas, and the possibility of the communication of disease germs from house to house."

Much less extreme views have been expressed by other English sanitarians, of the highest standing. Not to quote Carnelley and Haldane and Laws and Andrewes further, reference may be made to H. A. Roechling who in his admirable book on Sewer Gas and its Influence upon Health, (London, 1898) sums up as follows, after some initial hesitancy, "looking at the whole case and making all due allowances, it appears to the author that the chances of typhoid fever being brought about through the conveyance of the *Bacillus typhosus* in sewer air are somewhat remote."

Other authorities in England have been inclined to suspend judgment on the whole matter. Thus in the "Surveyor" for April 17, 1908, is the following editorial comment:

"As regards the bacteriological aspect of the question, there is so much difference in the results obtained from the experiments of the most eminent men that one can only look on and wonder. When one reads that, from the experiments of Mr. J. Parry-Laws and Dr. Andrewes on the micro-organisms of sewage and sewer air, it has been found that 'sewer air has no power of taking up the bacteria from the sewage with which it is in contact, and that, bacteriologically, the air of sewers is no worse than that of the street above, and that, in fact, the number of micro-organisms found may actually be less, while the types of germs are precisely those present in the external air, and not those of sewage; that, in fact, the *B. coli communis* is never found in sewer air, although it is present in such enormous numbers in sewage, and that the possibility of the existence of the typhoid bacillus in the air of sewers is infinitely remote! When one reads statements such as these and then compares them with the statements made by other eminent sanitarians, scientists and bacteriologists who are in opposition, it is difficult to arrive at any conclusion. With Mr. Read, we ask for 'a series of continuous experiments upon an actual drainage and sewage system,' lasting over a considerable period. Until then, argument is little better than beating the wind."

To sum up: the experiments carried out prior to 1896 showed that bacteria might be transferred from sewage to the air above,—but apparently only by active splashing or bubbling. The actual number of bacteria present in the air of sewers and drains was so small as to suggest that infection of this sort was inappreciable in amount. These experiments have convinced the sanitary authorities of Germany and the United States that the danger of transmitting disease germs in sewer air is negligible. In England, on the other hand, a strong body of sanitarians still maintains the reality of the danger.

II. RECENT EXPERIMENTAL RESULTS.

A little over a year ago, at the request of the National Association of Master-Plumbers, I attempted to gain some new experimental evidence as to the practical probability of the carriage of bacteria in sewer and drain air. The experiments of ten years before had not carried universal conviction, even in regard to the air of sewers; they threw still less light upon the conditions which exist in house drains themselves. It seemed therefore important to accumulate further data by actual observation.

My experiments were carried out with an experimental stack of four-inch soil pipe, 15 feet in height, connected at the bottom with an open running trap, and at the top with an exhaust fan.

Sewage could be discharged into the pipe by a branch connection entering two and a half feet above the running trap. Air was drawn up the pipe at high speeds by the exhaust fan, and immediately after stopping the fan, samples of air were collected from stop cocks at intervals along the stack.

Four conditions were studied. In one series of experiments the running trap was entirely sealed by pouring in 2 liters of sewage. Only the maximum draft of the fan, amounting to a flow of 790 feet per minute through the open pipe, could unseal the trap under these conditions. In one of two tests a slight increase in the number of bacteria was noted at the stop cock 2 feet above the trap after drawing the air through the sewage in this way. In a second series of experiments the running trap was partially sealed by pouring in a liter and a half of sewage. When air was drawn through this seal at a rate corresponding to 490 feet per minute, one or two germs per liter only appeared in the pipe, about the number found in normal air. With a rate of 620 feet on the other hand, 18 bacteria per liter appeared in one test 2 feet above the trap; 14, 7 feet above; and 5, 12 feet above. In another test characteristic intestinal bacteria appeared two feet above and 17 feet above the trap at the 620 rate. When air was drawn at high velocities over a liter of sewage in the bottom of the unsealed trap, no perceptible increase was noted in the bacterial content of the pipe. Finally, in a fourth series of tests, the lower two and a half feet of the stack were thoroughly wetted by allowing sewage to flow in through the side connection. Air drawn over this wetted surface showed in one case, with an air current of 790 feet per minute, a slight increase in the number of bacteria present, (5 per liter, 12 feet above). As a general result of these experiments I concluded that very strong currents of air could detach bacteria from sewage through which they bubbled or from moist surfaces over which they passed, so as to cause an appreciable increase in the bacterial content of the air. More moderate currents, such as would occur under actual conditions apparently failed to do so. Furthermore, even under the most extreme conditions the increase in the bacterial content of the drain air was small. Only three specific intestinal organisms were found in the air in my entire series of experiments. I concluded that "with such a high dilution the chance of infection through the drain air was but slight," and that "the carriage of disease germs from the air of a house drainage system is an improbable contingency."

At just about the time at which I made this report to the National Association of Master Plumbers another series of experiments of great importance was reported by an English bacteriologist, Major W. H. Horrocks of the Royal Army Medical Corps of Great Britain. This communication was entitled, "Experiments made to determine the conditions under which 'Specific' Bacteria derived from Sewage may be present in the Air of Ventilating Pipes, Drains, Inspection Chambers and Sewers." It was read before the Royal Society, February 7, 1907, and published in the Proceedings of the Royal Society, Series B, Vol. LXXIX., No. B 531, p. 255.

Major Horrocks approached the subject from the general standpoint of the English sanitarians, with the assumption that the carriage of bacteria by sewer and drain air was a probability at least. He stated his general object as follows: "Most sanitarians at the present time believe that when sewage is in a putrefactive condition and gas bubbles rising through it are bursting at the surface, bacteria may be carried into the air of drains and sewers. It is also considered possible that when sewage has dried on the surfaces of pipes, bacteria may be separated as dried particles and carried some distance by currents of air passing through the pipes. The following experiments were designed to ascertain whether there are any scientific facts on which to base these beliefs."

Major Horrocks' investigations were carried out at the fortress of Gibraltar. They consisted, in the main, in the exposure of Petri plates,—shallow glass dishes, filled with a nutrient medium, (nutrose agar),—in pipes, ventilating chambers, etc., over normal sewage or sewage specially infected with particular bacteria. After a given time the dishes were removed to an incubator and any germs which had fallen on them while in the pipe were identified by appropriate tests.

In the first series of experiments the *Bacillus prodigiosus* was used, a peculiar bacterium which forms characteristic red colonies on agar plates. An elbow was attached to one end of a 2-foot length of 6-inch pipe and a half-S trap to the other. On the upper side of the trap was set up a vertical stack 8 feet high. Plates were suspended in the vertical pipe, and soapy water, inoculated with an emulsion of *B. prodigiosus,* was poured through the horizontal pipe into the trap. After two hours the plates were removed from the vertical pipe, the highest of them having been placed 9 feet above the flowing liquid. Colonies of *B. prodigiosus* appeared on every plate. A similar experiment was then carried out with a catch pit on the storm water system of the town. An emulsion of *B. prodigiosus* was poured into the pit which was actively bubbling and fermenting. Plates suspended above the liquid for twenty-four hours showed numerous colonies of *B. prodigiosus,* while others exposed outside the pit did not.

A second series of experiments dealt with the carriage, by the air, of bacteria detached from dried surfaces. Three 2-foot lengths of 6-inch pipe were laid on the ground, and their interior was thoroughly wetted with a rich emulsion of *B. prodigiosus.* After drying, they were fitted together to form a vertical stack attached to a horizontal pipe through which sewage flowed slowly to keep up an air current. Plates suspended in the vertical pipe for 20 minutes were studded with colonies of *B. prodigiosus,* while control plates exposed to the air were free from such organisms.

The third, and most detailed, series of experiments dealt with the infection of air from flowing sewage. Repeated in various forms the essential points were as follows. Sewage, inoculated with cultures of the typhoid bacillus or of *B. prodigiosus,* was allowed to flow for half an hour through a horizontal 6-foot pipe to which a vertical pipe was connected at some intermediate position. Plates were exposed in the vertical pipe, usually for 24 hours, but in a few cases for 20 minutes only. The bacteria in the liquid flowing through the horizontal pipe were regularly recovered from the plates suspended in the vertical pipe. In some cases the vertical distance of the highest plate above the liquid was 11 feet 9 inches. A few very striking tests were made with actual drainage systems. Emulsions of *B. prodigiosus* were flushed out from water closets in two buildings and plates suspended in various parts of the ventilating pipes showed the characteristic colonies. These plates were exposed for 24 hours and the specific bacteria appeared fifty feet above the water closet in one case. A third experiment was made with a series of manholes and inspection chambers on the drainage system of a hospital block. An emulsion of *B. prodigiosus* was flushed into the sewer from one set of water closets and plates were exposed at various points. Those in open connection with the sewer showed characteristic colonies, while in disconnected inspection chambers none were found. Most striking of all, an unsuspected connection was discovered by the presence of the germ in one chamber where it was not expected. In some of the experiments, the plates were exposed for twenty minutes only.

The investigator then exposed plates in the ventilating pipe of the Military Hospital for 24 hours and in the inspection chamber of the main sewer of the town for 4 hours without adding any special bacteria to those normally present in the sewage. *B. coli,* the characteristic sewage organism, was found in both cases. Finally he made up a suspension of the stool of a typhoid patient, in 2 gallons of water and passed it 12 times slowly through a half-S trap. Plates suspended in a vertical pipe connected with the trap showed several colonies of the typhoid bacillus at heights of 2 feet and 3 feet 6 inches above the trap.

Major Horrocks' principal deduction from these experiments was stated as follows "Specific bacteria present in sewage may be ejected into the air of ventilation pipes, inspection chambers, drains and sewers by (a) the bursting of bubbles at the surface of the sewage, (b) the separation of dried particles from the walls of pipes, chambers and sewers, and probably by (c) the ejection of minute droplets from flowing sewage."

Very recently Dr. F. W. Andrewes of the English Local Government Board has extended and confirmed Major Horrocks' work in a still more striking manner. (Report on the Micro-Organisms present in Sewer Air and in the Air of Drains. Supplement to the Thirty-sixth Annual Report of the Local Government Board containing the Report of the Medical Officer for 1906-07, page 183). Dr. Andrewes found by the use of the differential fermentation tests devised by Mr. M. H. Gordon and so brilliantly applied by himself to the streptococci, that a number of cocci isolated from sewer and drain air were of characteristic sewage type and were different from those found in street air. Colon bacilli were also isolated from the air of a large drain and finally Horrocks' experiments with *B. prodigiosus* were repeated with similar results. The test organisms were recovered in large numbers at points of vigorous local splashing, and they were found once at a distance of 390 feet from the point of infection.

According to accepted opinions in Germany and the United States, the conclusions which might naturally be drawn from these investigations as to the possible danger of bacterial infection from sewer air were really revolutionary. In some quarters the Gibraltar experiments have provoked almost a return to the extreme dread of sewer air which characterized sanitary opinion thirty years ago. The Journal of the American Medical Association, (XLVIII, 1896), in commenting editorially upon Major Horrocks' experiments said in its issue of June 1, 1907: "He found, too, that typhoid bacilli could be given out by fresh sewage flowing through a well-drained sewer under natural conditions independently of bubbles and the separation of dried particles from the walls. The sewer peril, therefore, still exists and disconnecting traps are sanitary necessities. It is possible that we may still have to look to sewer emanations as the occasional cause of mysterious outbreaks of disease. Air-borne typhoid is a reality under other conditions, and apparently we shall have to recognize a possibility, though perhaps a remote one, of its conveyance by the old-fashioned sewer gas." In the Illinois State Board of Health Bulletin for May-June, 1907, the results of Major Horrocks were cited in defense of the statement made in a previous bulletin that: "There is no doubt, also, that sewer gas is a carrier of diphtheretic poison and that many outbreaks hence hold close relationship with defective drainage, sewers and cesspools," a statement which had been criticised by a reviewer in the American Journal of Public Hygiene, (XVII, 130 and 262).

A more conservative view on the other hand was expressed by the most competent sanitary authorities. Dr. C. V. Chapin of Providence, for example, reviewed Major Horrocks' paper as follows

"It has of late been believed that the chance of the transmission of the infectious diseases by sewer air is nil. A number of examinations have been made which have indicated that sewer air is comparatively free from germs, and attempts to isolate pathogenic bacteria from the air of sewers have given negative results. A recent work by Horrocks (Public Health, May, 1907, page 495), indicates that pathogenic germs may be carried by sewer air. Major Horrocks, among other numerous experiments, inoculated the sewage of a large military hospital at Gibraltar with a culture of *B. prodigiosus.* The culture was put into the water closets and the bacillus was recovered on plates suspended in the top of the soil pipe, in catch basins, and in manhole openings in the street many feet distant.

The experiments were carefully conducted, and control plates showed that the organism was not found in the air of Gibraltar. One should not, however, hastily jump to the conclusion that sewer air is commonly a vehicle of infection. There is practically no clinical evidence to show that typhoid fever and other infectious diseases are transmitted by sewer air, and, indeed, the evidence that diseases in general are often air-born is very slight. There is on the contrary evidence to show that minute infected droplets, or dust particles may float in the air in considerable numbers without causing disease. Until this subject has been further studied it is to be hoped that health officers will not be in a hurry to resuscitate the sewer gas bogey." (American Journal of Public Hygiene, XVII., 296).

III. REPETITION OF HORROCKS' EXPERIMENTS.

Experimental results which conflict with common experience may justly be received with some scepticism. Dr. Chapin, and others who hold with him, have ground for feeling that if bacteria are easily carried by sewer air there should be sound epidemiological evidence of such transmission. Further more, it must be remembered that all previous examinations of sewer and drain air under normal conditions have shown it to be singularly free from germ life and have indicated that the bacteria present are as a rule air forms rather than those characteristic of sewage.

Nevertheless experiments carried out with such apparent care as those made at Gibraltar and in England deserve careful consideration. The eminent position of Major Horrocks' and Dr. Andrewes lends great weight to their conclusions; and the negative results of the control experiments reported make it unlikely that the work could have been vitiated by any experimental errors. The conditions in Major Horrocks' experiments differed somewhat from those studied by other observers. In particular the promotion of active bubbling by the addition of soap formed a part of most, though not all, of his tests. This particular phase of the subject was not studied in my earlier work, as I used the ordinary sewage of Boston as it flows in the sewers, and this sewage is rendered hard by the leakage of sea water and does not easily foam. Again, different students of this problem have adopted somewhat different methods of isolating bacteria. Here Major Horrocks' procedure was less careful than might have been desirable. The method of exposing plates freely to the air may easily lead to contamination. In arranging an open plate in a wire cage and letting it down a ventilating pipe, an experimenter who has been working with *B. prodigiosus,* for example, runs many chances of contaminating the plate from hands or clothing. With long periods of exposure, such as twenty-four hours, the danger of contamination from dust or flies is of even more serious importance.

In the autumn of 1907 I began a new series of experiments, with the idea of clearing up the apparent contradiction between Major Horrocks' results and my own; and first I attempted to repeat Horrocks' experiments as closely as possible. A preliminary series of tests was made in a boat chamber of the main sewer of the South Metropolitan District of Boston. The boat chamber is entered from the side by a flight of about twenty-five stone steps extending downward from the street; and the stream of sewage flows by the bottom at times of low flow and backs up the steps in a stagnant eddying pool when the sewer is more nearly full.

On October 8, 1907, Petri plates, flat dishes 2.5 inches in diameter, containing a nutrient medium, were exposed for varying periods of time on the second step above the sewage which was standing at a high level. The plates were made with litmus-lactose agar and after exposure were incubated at 37°; so that any organisms which fell upon them could develop into colonies. The acid forming organisms characteristic of sewage, (*B. coli* group), could thus be easily detected.

The following numbers of colonies were counted on plates exposed for various periods; 5 minutes, 12 colonies; 10 minutes, 10 colonies; 15 minutes, 10 colonies; 20 minutes, 30 colonies; 25 minutes, 14 colonies; 30 minutes, 23 colonies; 35 minutes, 20 colonies; 40 minutes, 12 colonies; 45 minutes, 30 colonies; 50 minutes, 30 colonies; 55 minutes, 33 colonies; 60 minutes, 34 colonies. Control plates exposed in the street above showed 57 colonies after 35 minutes and 80 colonies after 60 minutes. In no case did any red colonies of sewage bacteria appear.

On October 18, this experiment was repeated, but the plates were exposed on the ninth step above the sewage stream. The flow on this day was low and the air of the street dusty. All counts were higher. The total number of colonies, and the number of red colonies, found after various periods, were as follows: In the boat chamber: 5 minutes, 15 colonies, 6 red colonies; 10 minutes, 47 colonies, 16 red colonies; 15 minutes, 49 colonies, 16 red colonies; 20 minutes, 70 colonies, 30 red colonies; 25 minutes, 170 colonies, 34 red colonies; 30 minutes, 141 colonies, 36 red colonies; 35 minutes, 133 colonies, 28 red colonies; 40 minutes, 250 colonies, 50 red colonies; 45 minutes, 240 colonies, 60 red

colonies; 50 minutes, 300 colonies, 75 red colonies; 55 minutes, 250 colonies, 71 red colonies; 60 minutes 225 colonies, 50 red colonies. In this series *B. coli.* was isolated and identified from each plate. Control plates, exposed in the street above for 20 minutes showed 250 colonies, and 20 red colonies with *B. coli* present. It seemed therefore probable that the bacteria in the boat chamber came from street dust blown down the steps.

On October 25, plates were exposed at different points on the flight of steps leading from the boat chamber to the street. Colon bacilli appeared in each case. On the tenth step above the sewage the counts for different periods of exposure were as follows: 5 minutes, 64 colonies, 2 red colonies; 10 minutes, 60 colonies, 10 red colonies; 15 minutes, 66 colonies, 7 red colonies; 20 minutes, 120 colonies, 7 red colonies; 25 minutes, 170 colonies, 16 red colonies; 30 minutes, 74 colonies, 23 red colonies; 35 minutes, 48 colonies, 6 red colonies; 40 minutes, 75 colonies, 5 red colonies; 45 minutes, 110 colonies, 16 red colonies; 50 minutes, 114 colonies, 18 red colonies; 55 minutes 161 colonies, 14 red colonies. The plates on the other steps were exposed for 20 minutes only, and showed after that period the following numbers: on the 13th step, 54 colonies and 4 red colonies; on the 15th step, 74 colonies and 5 red colonies; on the 17th step, 68 colonies and 6 red colonies; on the 19th step, 70 colonies and 12 red colonies; on the 21st step, 94 colonies and 10 red colonies. Plates exposed on the top step were uncountable. The total number of bacteria, and the number of colon bacilli increased in proportion as one approached the street and left the sewage behind. The principal source of intestinal bacteria was clearly street dust rather than sewer air.

These preliminary tests, as far as they went, furnished no evidence that the air of the boat chamber was polluted by bacteria from the sewage stream. The next series of experiments was carried out with a pipe system modeled as closely as possible after one of the systems used in Horrock's investigation. Its general arrangement is shown in Figure 1. It consisted of a half-S trap of 6-inch tile drain pipe, connected with a bend. Just above the trap was attached a horizontal stack composed of four 2-foot pieces of 6-inch pipe. In each experiment a foaming emulsion of soap and tap water was prepared and infected, either with a culture of *B. prodigiosus*, a culture of *B. coli* or a suspension of feces. This liquid, to a volume of four liters, was poured into the open end of the bend and through the trap. Plates were suspended at four levels in the vertical pipe, 2 feet, 4 feet, 6 feet and 8 feet above the surface of the liquid in the trap. Nine control plates were exposed in different parts of the laboratory at points which were approximately the same in each experiment. The period of exposure was 1 1-2 hours in experiments 9, 10 and 11, and 2 hours in all other cases.

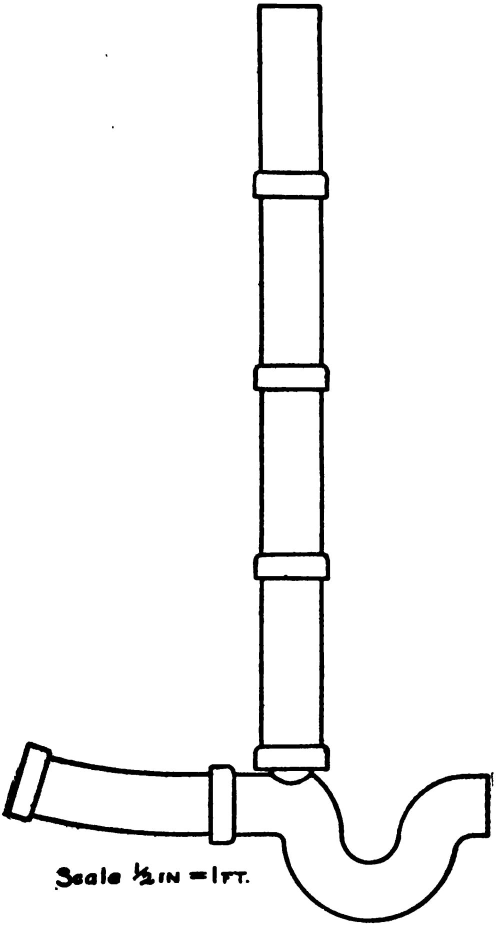

Figure 1.—Diagram of Pipe System used in repeating Major Horrocks' Experiments.

The results of these experiments, as regards total colonies on the plates, are shown in Table I. below.

TABLE I

NUMBER OF COLONIES ON PLATES EXPOSED IN VENTILATING PIPE AND IN ROOM OUTSIDE

No. of Experiment	Material	Plates in Pipe. 1	2	3	4	Plates in Room 5	6	7	8	9	10	11	12	13
1	*B. prodigiosus*	20	30	26	48	—	—	68	90	118	67	88	—	69
2	Feces	5	4	4	2	5	4	1	3	4	4	1	1	6
3	*B. prodigiosus*	77	69	77	59	140	190	136	301	175	548	254	322	182
4	*B. prodigiosus*	112	94	105	98	—	228	—	244	163	598	350	337	194
5	Feces	35	18	0	62	8	17	6	5	13	87	30	24	21
6	*B. prodigiosus*	780	780	540	780	1020	840	1020	960	1080	2940	2400	1690	1200
7	*B. prodigiosus*	326	148	212	153	350	420	600	600	480	540	1090	720	660
8	*B. coli*	0	0	0	0	18	12	13	—	11	14	10	20	13
9	*B. prodigiosus*	44	22	29	38	105	132	162	91	94	202	172	128	74
10	*B. coli*	4	1	0	1	6	8	4	1	2	32	10	4	—
11	*B. coli*	7	8	10	3	17	11	12	10	7	9	10	8	12
12	*B. coli*	5	6	5	5	9	12	8	7	16	4	11	10	6
13	*B. coli*	10	10	6	2	9	16	9	12	9	7	5	8	10

Plates 1—4 in each case were the ones suspended in the vertical pipe above the infected liquid. 1 was 2 feet above, 2, 4 feet above, 3, 6 feet above, and 4, 8 feet above its surface. No. 13 was just outside the inlet of the bend into which the liquid was poured. Nos. 11 and 12 were just outside the outlet of the trap from which it flowed. Nos. 5—10 were in other parts of the laboratory.

The pipe system was taken to pieces and disinfected by washing the inside of each piece with corrosive sublimate solution after each experiment.

These total counts show that in general the bacteria in the pipe fluctuated with the general bacterial content of the laboratory, being somewhat lower on the whole, as would naturally be expected. The important thing, however, is the distribution of the specific organisms with which the liquid in the pipe had been infected. When suspensions of feces or of *B. coli* were used, the plates after exposure were incubated at 37 degrees and acid colonies present were examined to see whether they corresponded with the intestinal forms. When a suspension of *B. prodigiosus* was used, plates were incubated at 20 degrees and examined for characteristic red colonies. This difference of incubation temperature accounts for the much larger number of total colonies shown for *B. prodigiosus* tests in Table 1, since these were 20 degree counts.

The result of the tests as regards the distribution of specific organisms is indicated below:

TABLE II

DISTRIBUTION OF COLONIES OF *B. COLI* ON PLATES EXPOSED IN VENTILATING PIPE AND IN ROOM

	Plates in Pipe				Plates in Room								
No. of Experiment	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	—	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	3	2	0	1	0	0	0	0	0	0	0	0	0
13	5	2	1	1	0	0	0	0	0	0	0	0	0

In no case were colonies of colon bacilli apparent on plates exposed to the general air of the laboratory. In the first five experiments none of the specific bacteria appeared in the pipe; but in each of the last two experiments *B. coli* appeared on three of the four plates exposed in the pipe, in greatest numbers, (3 and 5 colonies, respectively), on the plates nearest the infected liquid.

TABLE III

DISTRIBUTION OF COLONIES OF *B. PRODIGIOSUS* ON PLATES EXPOSED IN VENTILATING PIPE AND IN ROOM

	Plates in Pipe				Plates in Room								
No. of Experiment	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	1	0	0	0	0	0	0	0	0	0	0
6	6	3	1	1	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
9	3	0	0	1	0	0	0	0	0	0	0	0	0

The results of the tests carried out with *B. prodigiosus* were essentially the same, as indicated in Table III. In three tests no characteristic colonies appeared on any plates; in the other three tests positive results were obtained in the pipe. The plates placed two feet above the infected liquid showed 6, 3 and 1 colony respectively. One plate four feet above showed three colonies. A single colony appeared on two occasions, six feet and eight feet above the liquid.

IV. OBSERVATIONS ON THE VELOCITY OF AIR CURRENTS NECESSARY TO TRANSPORT BACTERIA

Granting that bacteria may be discharged from the surface of a foaming liquid into the air above, it seemed *a priori* probable that even slight currents of air could transport them to almost any distance. I wished however to test this presumption by actual observation; and a few experiments were conducted with this end in view.

The velocity of an air current which will just carry a minute solid body must exceed the power of gravity upon the body. It is clear that bacteria can be carried upward through a pipe by a current, of a velocity just exceeding the rate at which the bacteria would fall in quiet air. The latter phenomenon, the falling of small particles through the air, takes place according to Stokes' law, which is expressed as follows:*

$$v=\frac{2}{9}\frac{gr^2}{m}(o-p)$$

Where v is the velocity of a particle (a sphere) of radius r and density o falling through a fluid of viscosity m and density p; g is the gravitation constant. Calling $g=980$; p (for air at about 20° C)$=.00018$ and calling the density of the falling particles$=1$ which is approximately correct for the bacteria, the equation becomes,

$$v=1200000\ r^2$$

Since all the quantities are expressed in C. G. S. unites v is in centimeters per second. Hence a sphere of density 1 and radius

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* I am indebted to the kindness of Prof. Gilbert N. Lewis of the Massachusetts Institute of Technology for the application of this formula.

.001 cm. will drop through the air at the rate of about 1.2 cm. per sec. A sphere of radius .0001 cm. will fall .012 cm. per sec., etc.

A small bacterium like *B. prodigiosus*, has a radius somewhat less than .0001 cm. and should therefore fall through quiet air at a rate a little under .012 cm. per second, which is equivalent to about 17 inches per hour. An air current of even such slight velocity as this might therefore be expected to carry bacteria.

In order to test this point I had an opening bored into the side of a large bottle so that a rich emulsion of a culture of *B. prodigiosus* could be sprayed into the bottle at about its center. The neck of the bottle was closed by a cork stopper perforated to receive a glass tube of 1.7 cm. inside diameter. This tube in the first experiment was 75 cm. long, In the second and third experiments a smaller flask was used instead of the bottle and the tube passing through the stopper was only 10 cm. long. In all other respects the arrangements were the same.

The precedure in making an experiment was as follows; the top of the glass tube, (which has previously been sterilized), was connected by sterile tubing with the inlet of a Culture Bottle, (described later in Section V). An emulsion of *B. prodigiosus* was sprayed into the flask and a measured amount of the air in the flask was drawn very slowly through the 1.7 cm. glass tube, and the much smaller rubber tubing, into the Culture Bottle. The air was aspirated by means of a suction bottle from which the outflow was regulated by a pinchcock or by a capillary tube. In each experiment several samples of air were collected in this way at progressively increasing rates. The presence of *B. prodigiosus* colonies in the Culture Bottle showed that germs had been drawn up through the 1.7 cm. tube, at an average linear rate determined by dividing the rate of overflow from the suction bottle by the area of the tube, (2.3 square centimeters).

In the first experiment conducted, four one-liter samples were drawn through the long tube in 3, 6, 18 and 43 minutes, respectively. *B. prodigiosus* colonies appeared in great numbers in the culture bottles; 9000 per liter appeared in the three minute sample 3100 in the six-minute sample; 4250 per liter in the 18 minute sample; and 3300 per liter in the 43 minute sample. The linear flow through the 1.7 cm. tube in the four cases was approximately 5.5 cm. per sec., 2.7 cm. per sec., .9 cm. per sec. and .39 cm. per sec.; or 7920 inches per hour; 3900 inches per hour; 1300 inches per hour and 560 inches per hour. These rather high rates of flow evidently carried the bacteria in great numbers.

A second series of experiments was carried out as noted above with a smaller apparatus, arranged for the examination of smaller volumes of air, drawn up at lower speeds. 100 cc. samples were examined in this series and four rates were tested as follows; .07 cm. per sec., .08 cm. per sec.; .28 cm. per sec.; and .56 cm. per sec.; corresponding to rates of 100 inches per hour, 115 inches per hour, 403 inches per hour and 806 inches per hour. A single colony of *B. prodigiosus* appeared in the Culture Bottle of the last series and none in the others. It appeared as if the limiting velocity which would just carry bacteria had been reached.

The third series of experiments, however, showed that this was not the case, and the failure to find bacteria in this instance must be attributed to imperfect distribution of the emulsion sprayed into the flask.

The third series of tests was made in exactly the same way as the second, except that a wider range of air velocities was included. Ten samples were examined, the velocities being indicated in Table IV. below.

TABLE IV

VELOCITY OF AIR CURRENTS CAPABLE OF CARRYING BACTERIA

Number	Time for 100 cc in minutes	Velocity in 1.7 cm. tube	
		Centimeters per second	Inches per hour
1	32	.05	72
2	32	.05	72
3	15	.11	158
4	15	.11	158
5	12	.14	202
6	6	.28	404
7	3.3	.50	720
8	3	.56	808
9	2	.83	1195
10	1.3	1.28	1843

In every case large numbers of *B. prodigiosus* colonies appeared in the Culture Bottles. 1600 per 100 cc. were counted in Experiment 1 and 800 in Experiment 2; at the higher rates the number of colonies was so large as to be uncountable.

My experiments did not extend to the minimum air velocities which should theoretically be adequate to transport bacteria, (17 inches per hour). They did show that currents a little over four times as strong, (72 inches per hour), would carry enormous numbers of bacteria in the form in which they are discharged in the fine spray from an atomizer. There was a slight inaccuracy in my observations due to variations of head in the suction bottle. Calculation and control experiments showed that this error amounted to 40 per cent. at some of the higher rates, the actual velocity at the beginning of the experiment being by that amount in excess of the mean velocity for the test. At the least velocity, however, this error did not exceed 10 per cent.; and it is safe to conclude that air velocities of less than .07 cm. per second or less than 100 inches per hour, will carry bacteria in the form in which they are sprayed from an atomizer.

Applying the formula for velocity of falling particles, previously quoted, it appears that the droplets containing the bacteria in these experiments must have been less than .0005 cm. in diameter. If the bacteria are discharged from the surface of foaming liquids in droplets as small as this, it is clear that they may be transported by air currents of velocity as low as 100 inches per hour.

V. PRELIMINARY TESTS OF QUANTITATIVE METHODS FOR ENUMERATING BACTERIA IN AIR

The general result of the experiments reported in Sections III and IV was to confirm the main contention of Major Horrocks,—that specific bacteria may be ejected from a foaming soapy sewage into the air above, and once in the air may be carried to considerable distances. The proportion of positive results obtained in Section III was small, however. With an exposure of two hours over a soapy liquid richly inoculated from artificial cultures, a total of 31 specific bacteria were isolated from 52 plates. The question at once suggested itself whether the whole question at issue might not be a quantitative one. Horrocks, by exposing plates over infected sewage, found that some of the bacteria present could be isolated from the air. Other observers who had examined sewer and drain air under natural conditions by quantitative methods had failed to find sewage bacteria in appreciable numbers. It might be possible that a few bacteria do get into the air above foaming sewage; but that their number is so small as not to effect the bacterial content of the air as a whole, as determined by ordinary quantitative methods. This appeared to be the next point for investigation.

Before attempting such careful quantitative studies as seemed necessary for clearing up the contradictions which surround this subject, it was obviously important to make a careful test of the accuracy of the bacteriological methods involved.

The development of bacteriological methods for the examination of air has not attracted wide attention in recent years; and this branch of bacteriology is far behind the related subject of water bacteriology in its technique and interpretation.

The bacteriological examination of air goes back in its origin to the earliest days of the science. In 1860 Pasteur filtered air through asbestos, washed out the material collected on the filtering material and examined it under the microscope. This was a crude and very imperfect method as far as the bacteria were concerned. At about the same time, however, he developed another process, cumbrous, but of considerable accuracy. He heated flasks of nutrient media so as to sterilize them and drive out the air and while still hot, sealed the necks of the flasks. When air was to be examined the narrow neck of a flask was broken. A more or less definite volume of air rushed in and any germs present fell into the liquid and there multiplied. The number of flasks, out of a series, which showed bacterial growth, gave a measure of the number of organisms in the air. This was one of the methods employed by the French bacteriologist, Miquel, in his numerous and important investigations. He drew air through flasks of nutrient liquid, (1876), placing a filter of glass wool at the outlet of the flask to catch any germs which passed the liquid.

In 1881 Robert Koch introduced the plate method of bacterial cultivation which depends on the fact that bacteria in a nutrient jelly grow and multiply so as to form visible colonies, by counting which, the number of individual bacteria originally present, is determined. Koch himself applied his method to the examination of air by placing a culture plate of nutrient gelatin at the bottom of a glass cylinder in which a known volume of air was allowed to settle quietly. The number of colonies corresponded in a general way to the bacterial content of the air in the cylinder, but the method was obviously very inaccurate from the quantitative standpoint.

In 1883 Hesse attempted to improve the solid culture method by spreading his nutrient medium over the inside of a long horizontal glass tube and drawing a measured amount of air slowly through it. Most of the bacteria present settled out on the walls and formed colonies which could be easily enumerated. The tube was a cumbrous apparatus, however, and it was doubtful whether the bacteria did all settle out unless the velocity was extremely slow.

In 1888, Petri introduced the method which has since been most widely used. He drew a measured amount of air through a layer of fine sand, which he found would retain most of the bacteria present by adhesion to its surfaces. He then washed the bacteria off by shaking the sand in sterile water, distributed known portions of the water in Koch plates and counted the colonies. (R. J. Petri, Eine neue Methode Bacterien und Pilzsporen in der Luft nachzuweisen und zu zählen, Zeitschrift fur Hygiene, 1888, III 1). At about the same time that Petri was working, Frankland in England independently developed a similar method in which sugar was used as a filtering material instead of sand. In the same year, 1888, Sedgwick and Tucker devised a simple and ingenious apparatus for carrying out air examination by this general method, which has since come into common use in this country.

For the last twenty-five years almost nothing has been added to our knowledge of methods for bacteriological examination of air. Workers have relied almost exclusively on two procedures, the simple exposure of plates and the sand filter method. The former, more primitive, method was the one used by Horrocks. It offers an extremely delicate test for specific kinds of bacteria; but as pointed out above, it is open to grave dangers of contamination. Furthermore, it has no quantitative basis, since the number of bacteria found is not related to any particular volume of air. The other method in common use is a modification of the sand filter method of Petri. It involves the filtration through asbestos, sand, sugar, etc., of a measured volume of air; the washing of the filtering material with sterile water; and the plating of aliquot portions of the wash water on nutrient media. Petri recommended sand between .25 and .5 mm. arranged in two layers each 3 cm. deep, in a tube 1.5-1.8 cm. in diameter. He stated that the rate of filtration should not exceed 10 litres in 1-2 minutes. In recent years we have had no careful studies of the extent to which bacteria may be drawn through sand and lost under given conditions; and there has arisen some scepticism as to the reliance to be placed upon the whole procedure. In the most important investigation of air recently carried out in this country, the study of the air of the New York subway, Soper used both the plate method and the sand filter method. The sand grains used were "about half a millimeter in diameter" and the sand layer 5 cm. deep, (Technology Quarterly, XX, 58). In discussing these methods, in another paper this author said "as is well known, there is no precise way to determine the numbers of bacteria in air," (Journal of Infectious Diseases Supplement No. 3, 1907, p. 82.)

Obviously if the sand filter allows any important proportion of bacteria to pass, the results of the observers who reported low bacterial numbers in drains and sewers must be discounted. In my own earlier work, reported to the National Association of Master Plumbers in 1907, I relied upon the sand filter method; and in view of the results of Major Horrocks, it seemed desirable to revise the detail of the technique with considerable care. In the course of the experiments I developed a modified method of air examination which seems to combine the quantitative results of sand filtration with the directness and simplicity of the plate method. Hesse did this after a fashion by slowly aspirating air through a long roll-tube, the walls of which were covered with melted gelatin. There was, however, a possibility in such an apparatus that bacteria might be drawn through without settling out on the walls. My method was really a modification of Hesse's with an increase in the size of the culture vessel relative to the sample of air; or from another standpoint, it was a return to the original procedure of Koch with such precautions as would prevent contamination and secure quantitative results.

I used two liter-and-a-half bottles, arranged as shown in Figure 11. On the bottom of each was a layer of nutrient gelatin and the tubing was adjusted so that a measured volume of air could be drawn through the two bottles in succession, by the action of a water-suction bottle, shown inverted on the right of the figure. In practise any desired amount of water, generally one liter, is placed in the suction bottle and by slowly inverting it, a corresponding volume of air is drawn from the bottom of the second culture bottle. The same volume of air passes from the bottom of the first bottle into the top of the second, and from the outer air into the top of the first bottle. A known amount of air is thus drawn into the first bottle and the bacteria present settle out and form colonies on the gelatin. The volume of air examined being less than the capacity of either bottle, most of the bac-

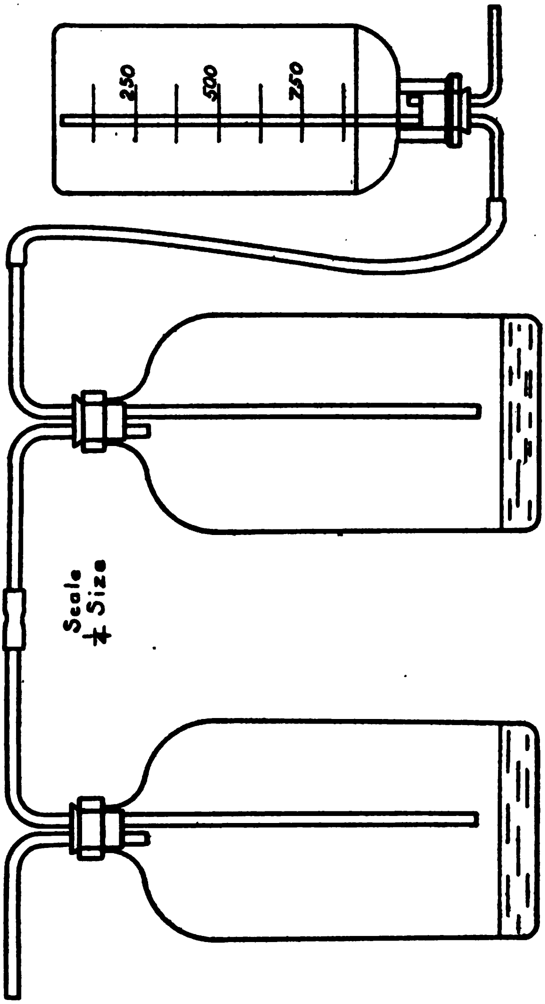

FIGURE II.
Diagram of Apparatus used in the Culture Bottle Method of enumerating Bacteria in Air

teria collected remain in the first. A few, which are carried down by direct short currents, are caught in the second bottle. The results of a few examinations made by this method are shown in Table V below.

TABLE V

AIR EXAMINATION BY CULTURE BOTTLE METHOD

Air	Sample, c.c.	Colonies first bottle	Colonies second bottle	Bacteria per liter
Normal Street Air	1500	4	0	3
Air above foaming soapy emulsion of *B. prodigiosus*	1000	1	0	1
	1000	1	1	2
	1000	1	0	1
	1000	3	0	3
	1000	1	0	1
Air sprayed with suspension of *B. coli*	100	73	1	740
	100	984	91	10750
	100	394	69	4630
Air sprayed with suspension of *B. prodigiosus*	100	492	3	4950
	100	320	34	3540
	100	1188	120	13080

The number of bacteria reaching the second bottle is evidently small, in most cases less than 10 per cent., and the number lost by being drawn through the second bottle must be negligible. With the exception of the possibility that bacteria may settle on the sides of the bottles, the method should give a complete account of all bacteria present which will grow under ordinary conditions of cultivation.

The Culture Bottle method was devised primarily as a check on the Sand Filter method; and two types of sand filters were used for comparison. The first was the classic Sedgwick-Tucker apparatus which consisted of a glass tube 15 cm. long and 4 cm. in diameter, opening at one end into a smaller tube 10 cm. long and .5 cm. in diameter. A layer of 5 cm. of sand was supported in the small tube by wire gauze. A measured amount of air was drawn through, entering the larger tube and passing out through the sand. The sand, with the bacteria filtered out, was shaken down into the large tube, melted gelatin was added and by rolling the tube on ice, the gelatin with the sand and bacteria was cooled on its inner surface. The sand used in this filter was between .5 mm. and 1.0 in diameter.

The other type of filter tested was the one which I used a year ago. It consisted of two short tubes 1.5 cm. in diameter, arranged in tandem, each containing 2.5 cm. of sand, between .1 mm. and .3 mm. in diameter. The sand in each tube was supported by bolting cloth on a perforated rubber stopper and the tubes were connected by rubber tubing. The apparatus is shown in Figure III. After drawing air through this filter, the sand from each tube was shaken out into ten cubic centimeters of sterile water and after thorough agitation aliquot portions of the water were plated. This method is essentially the one used by Soper and by most recent observers.

Each of these filter methods is open to possibilities of error. Bacteria may be drawn completely through the filtering layer in either case; and in the second method there is danger that bacteria filtered out may not be separated from the sand or bolting cloth. My object was to find out how serious these errors are by direct comparison with the Culture Bottle method. For this purpose a number of examinations were made, of normal air, and of air artificially infected with bacteria by spraying with emulsified cultures. With the filtration method samples of 750 cc. to 1500 cc. were slowly drawn through the sand, the filtration occupying 2-3 minutes. With the Culture Bottles samples of 100 cc. were generally used and the air was drawn in more rapidly. The general results obtained may be shown best by quoting a few typical experiments in detail.

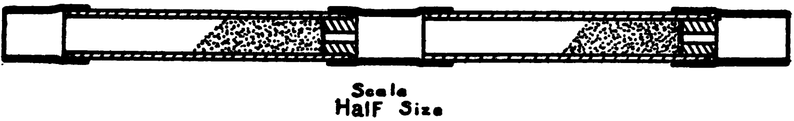

FIGURE III.
Diagram of Apparatus used in the Sand Filter Method of enumerating Bacteria in Air

Experiment III. Examinations of air of a city street on a winter's day. Four successive samples taken at intervals of perhaps fifteen minutes showed (1), 3 bacteria per liter, by Culture Bottle Method; (2), 17 bacteria per liter by filtration method, (fine sand); (3), 23 bacteria per liter by filtration method, (fine sand); (4), 94 bacteria per liter by filtration method (fine sand). Apparently the number of bacteria in the air was increasing during this experiment; but the results by the two methods are concordant.

Experiment IV. A suspension of a culture of *B. coli* was sprayed into a box and five samples taken at intervals of about ten minutes. The results were as follows: (1), 2640 per liter by filtration method, (fine sand); (2), 100 by filtration method, (fine sand); (3), 740 by Culture Bottle method; (4), 40 by Culture Bottle method; (5), 0 by sand filter method (fine sand). Evidently the bacteria were settling out rapidly. With the exception of the low sand filter count in No. 2 the results of the two methods check fairly well.

Experiment V. *B. coli* was sprayed into a box four times, at intervals of about ten minutes, a sample of the air being examined after each spraying. The results were as follows: (1), 175 bacteria per liter, by sand filtration, (coarse sand); (2), 4300 per liter by sand filtration (fine sand); (3), 4000 per liter by sand filtration, (fine sand); (4), 10,750 per liter by Culture Bottle method. Very probably the repeated spraying more than balanced the settling out and the number of bacteria in the air of the box actually increased. The first result with the coarse sand is, however, clearly too low.

Experiment VI. *B. prodigiosus* was sprayed into a box three times. The first two samples were examined after the first spraying, the third and fourth samples after the second and third sprayings, respectively. Results: (1), 15,000 bacteria per liter, by sand filtration, (fine sand); (2), 14,000 per liter by Culture Bottle method; (3), 5300 per liter by sand filtration, (coarse sand); (4), 14,000 per liter by sand filtration, (fine sand). Again the filtration method checked with the Culture Bottle method when fine sand was used, but gave low results with the coarse sand.

These experiments, and others of the same sort, seemed to indicate that sand filtration gives reasonably accurate results if the sand used be as fine as .3 mm. The crucial test of this point, however, must be made by drawing a given sample of air through sand filters and a Culture Bottle, so arranged in tandem that the bacteria which pass the sand shall be collected in the bottle. Table VI. below shows a series of such experiments and makes it clear that the efficiency of the filtration method depends upon the size of sand grain employed.

TABLE VI

RELATIVE NUMBER OF BACTERIA PASSING THROUGH SAND FILTERS AND RETAINED IN THEM

Air examined	Bacteria per liter retained in filter		Bacteria per liter passing filter
	Two 2.5 cm layers of .1 — .3 mm. sand	One 5 cm. layer of .5 — 1. mm. sand	
Suspension *B. prodigiosus*	100		2
Street air	94		1
Suspension *B. coli*	2640		12
"		175	304
"	4000		37
Suspension *B. prodigiosus*		1700	3500
"	14000		2400
Suspension, *B. coli*	40		12
"	90		15
"		165	105

In seven tests with tandem sand filters, each containing 2.5 cm. of sand, with grains between .1 and .3 in diameter, the bacteria passing the sand were,—once 30 per cent. of the number retained by the sand; twice 17 per cent., once 2 per cent., and three times 1 per cent. or less. On the other hand, in three tests with the Sedgwick-Tucker apparatus holding a single layer of sand, 2 cm. deep with grains between .5 mm. and 1.0 mm., nearly half the bacteria present passed the sand in one case and about two-thirds escaped in the other two instances.

It seems clear that sand over .5 mm. in diameter is inadequate for filtering out bacteria. On the other hand a sand finer than .3 mm. is generally efficient. It is of course obvious that sand of either size cannot operate in the removal of bacteria by any process which can properly be called straining. In an editorial discussion of the removal of fine particles from water the Engineering News, (LIX, 344), has described the phenomenon as "adhesion"; and the term deserves general acceptance in this connection. The size of the sand must affect the removal of fine particles in two ways. First in a given depth the number of surface contacts which permit adhesion, must vary inversely with the size of the particles. Second, the velocity of flow, which tends to tear off adhering particles, must, under given conditions, increase with the size of the particles. Coarse sand might therefore be used with success by filtering through a deeper layer, and by cutting down the rate of flow.

On the whole, it is clear that the Culture Bottle method, although cumbrous, is somewhat superior to the Sand Filter method, where the highest accuracy is desired. To avoid any possibility of error, I have used it in all succeeding experiments. At the same time the comparative tests reported show that the errors of the Filter method are not serious if the sand used be fine enough. The results of observers who have used the sand method, may therefore be accepted as reliable in their general conclusions.

VI. ENUMERATION OF BACTERIA IN AIR OVER FOAMING LIQUIDS.

Horrocks' experiments, and my own repetition of them, showed that specific bacteria could be recovered from the air over foaming liquids. On the other hand, quantitative studies showed that sewage bacteria are rarely present in the air of sewers and ventilating pipes under normal conditions. It was of vital importance to determine the meaning of this apparent contradiction. It seemed to me that it might be due to one of two possibilities. Either the artificial infection and the addition of soap to produce foaming, common to most, (but not all) ,of Horrocks' experiments, caused an abnormal number of bacteria to be discharged into the air; or even under such conditions the bacteria, though they may be detected by the plate method, are present in such small numbers as not appreciably to affect the air of the sewer as a whole.

In order to test this point, I set out to examine, under carefully controlled conditions, the air over liquids of various sorts. My original plan was to test sewage, with and without the addition of soap to produce foaming, suspensions of feces in water with and without soap, and artificial emulsions of specific bacteria. I began with the most severe test, which was likely to show the largest possible numbers in the air; a suspension of a rich artificial culture of *B. prodigiosus* in water, to which enough soap had been added to make it foam vigorously. The results of this first series showed such slight infection of the air, that it was unnecessary to proceed to more rigorous tests.

Eight experiments were made upon this point, in February and March, 1908. In all cases the emulsion was made with tap water, to which a large excess of soap had been added, and the germ used was *Bacillus prodigiosus*. The emulsion contained from 200,000 to 5,000,000 bacteria per c.c. in different experiments; and it was agitated so as to form a layer of foam from 1-4 in. to 1 1-2 inches deep on the surface.

In the first five experiments the infected emulsion was poured through a funnel into a glass chamber about 30 cm. in diameter and 17 cm. deep, with considerable splashing, as well as foaming. Three or four samples of air of one liter each were collected in each case from the chamber at a height of 3 cm. or less above the foam, the first being taken immediately after the liquid was poured in, the others at intervals during the next hour or so.

The results of these experiments, with those of the other three, which will be described later, are shown below in Table VII. In three of the five cases not a single colony of *B. prodigiosus* appeared in the four liters examined in spite of the fact that hundreds of thousands were present in each centimeter of the liquid below. In Experiment III. a single *B. prodigiosus* appeared in one of the four liters; and in Experiment IV. one liter showed one, and a second showed three.

The act of sampling, in drawing off four liters of air from the chamber of course created air currents across the surface of the foaming liquid in these experiments. In order to observe the effect of more active circulation of air three more experiments were made in which the foaming emulsion was poured into a glass vessel four inches deep and left open in the laboratory. The surface of the foam was a little over the edge of the vessel in each instance, and in order to make all conditions severe the samples of air were taken from a point as close to the surface of the foam as possible. Samples were taken at intervals during a half hour period. In Experiment VI. two of the four samples showed no colonies; of the other two, each showed a single colony of *B. prodigiosus*.

In Experiment VII. the samples showed counts of 2, 3, 0 and 1 colonies per liter; but all were air bacteria and none *B. prodigiosus*. In Experiment VIII. three samples examined showed counts of 2, 1 and 2 colonies per liter; but again none were *B. prodigiosus*.

It is clear from these experiments that the number of bacteria discharged into the air over an infected liquid is extremely small, even under the most favorable conditions. With an actively foaming liquid containing hundreds of millions of bacteria per liter, 30 liters of air examined showed altogether only 7 of the bacteria in the emulsion below.

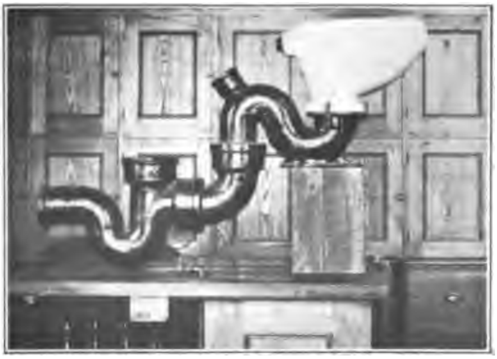

FIGURE V.
Photograph of Experimental Plumbing System.

Numbers of this magnitude can be detected by Horrock's plate method; but they would scarcely affect the general composition of drain and sewer air in a degree sufficient to be revealed by quantitative methods.

TABLE VII.

BACTERIA IN AIR OVER FOAMING LIQUIDS

	B. prodigiosus per liter				
Experiment	**In liquid**	**In air**			
1	530,000,000	0	0	0	0
2	680,000,000	0	0	0	0
3	930,000,000	0	1	0	0
4	5,000,000,000	0	1	3	0
5	1,000,000,000	0	0	0	0
6	2,700,000,000	1	0	0	1
7	1,800,000,000	0	0	0	
8	4.400,000,000	0	0	0	

VII. ENUMERATION OF BACTERIA IN PLUMBING PIPES OVER FOAMING AND SPLASHING LIQUIDS.

Major Horrocks' experiments, and the confirmatory tests reported in Section III., show that some bacteria are discharged from the surface of a foaming liquid and may be recovered from the air above. Once in the air, they may be transported by currents of quite low velocity, as shown in Section IV. On the other hand, the experiments discussed in Section VI. indicate that the numbers of bacteria discharged in this way are small. The air immediately over a quiet body of infected liquid covered with a deep layer of bursting bubbles showed only rare and slight contamination.

Under ordinary conditions the effect of foaming is reinforced by gross mechanical splashing, which might conceivably increase the tendency to discharge bacteria into the air in minute droplets. In order to test this point I made a series of experiments with the apparatus shown in Figures IV and V. It consisted of an ordinary porcelain water closet bowl set directly on an S-trap with a cleanout hole at its apex. The S-trap was connected at its lower end by a bend with an ordinary running trap.

A rich soapy emulsion of about 7 liters was made up, as in other tests, and infected with a culture of *B. prodigiosus.* This was poured as rapidly as possible into the bowl of the closet so that it rushed down through the pipe, foaming and splashing, finding its exit finally from the lower end of the running trap. A large cork stopper was placed in the cleanout hole, while the liquid was passing, but was removed immediately afterward. Liquid remained in the S-trap and closet bowl and in the running trap; and on the surface of this liquid was three or four inches of foam. A current of air passing in at the running trap and out at the clean-out was manifested by a slight cloud of vapor at the clean-out, (the water used in making up the emulsion being warm). Everything was therefore as favorable as possible for the appearance of bacteria from the infected liquid at the clean-out and in the upper opening of the running trap.

At both points samples of air were collected and examined by the Culture Bottle Method. Sampling point A, at the clean-out (See Figure IV), was about 9 in. from the liquid in the S-trap, and in the full course of a current of air from the pipe through which the foaming liquid had just passed. Sampling point B was 6 in. above the liquid in the running trap and often only 3 in. from the surface of the foam. Furthermore no attempt was made to sterilize the apparatus during the course of the experiments. Bacteria dried on the surface between two tests, (which were made three days apart), might therefore have been detached to increase the contamination of the adjacent air.

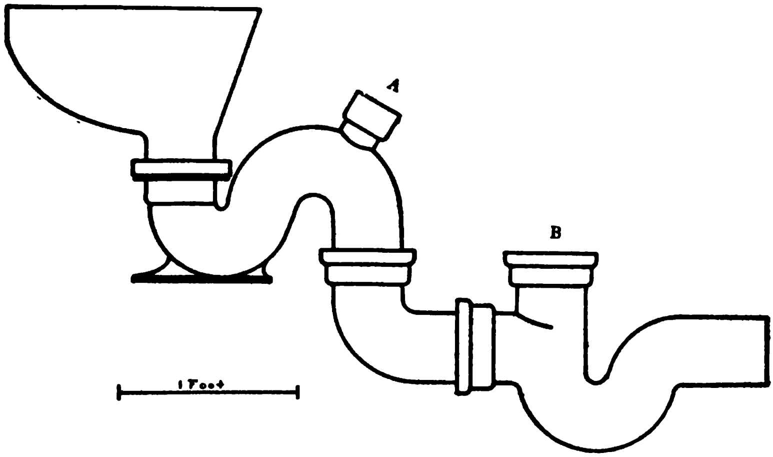

FIGURE IV.
Diagram of Experimental Plumbing System.

The general results as concerns total numbers of bacteria are shown below in Table VIII. Four to seven liters of air were examined in each Series, samples being taken alternately from the openings A and B. Sometimes the whole test was completed in fifteen minutes; sometimes the samples were taken at intervals of half an hour for a three-hour period. No important difference appeared in the results.

Table VIII. shows merely the total number of organisms in the air examined. The important thing of course was to determine the presence of the specific bacteria with which the liquid flowing through the system had been infected. All colonies which appeared in the bottles were therefore examined;

TABLE VIII.
TOTAL BACTERIA IN AIR OVER SPLASHING LIQUID

Sampling point	A				B		
I	1	1	1		0	2	0
II	1	11	1	2	1	3	4
III	3	1	1		0	1	1
IV	1	0	0		0	0	0
V	4	7	15		4	1	
VI	0	2	0		0	0	
VII	0	1	0		1	0	
VIII	2	1			0	0	

and with the exception of a single bottle all the colonies turned out to be those of the molds and common cocci of the air. In the second sample taken at the upper clean-out of the S-trap in Experiment II. the cultures proved to be *B. prodigiosus.*

TABLE IX
SPECIFIC BACTERIA IN AIR OVER FOAMING AND SPLASHING LIQUID

B. prodigiosus per liter

	Liquid	Air at A				Air at B		
I	1,300,000,000	0	0	0		0	0	0
II	300,000,000	0	11	0	0	0	0	0
III	—	0	0	0		0	0	0
IV	2,500,000,000	0	0	0		0	0	0
V	1,750,000,000	0	0	0		0	0	
VI	5,600,000,000	0	0	0		0	0	
VII	—	0	0	0		0	0	
VIII	2,100,000,000	0	0			0	0	

Table IX. shows the general quantitative results of the experiments, which may be summarized as follows: A richly infected liquid was prepared containing several billion bacteria per liter. This was beaten up with soap into a heavy foaming emulsion and was then poured rapidly through a water closet and two successive traps, splashing and foaming as it went. Forty-four liter samples of the air of the traps, were examined, from points 6 to 9 in. above the liquid. Forty-three of these samples showed none of the organisms in the liquid, and one showed a group of 11 colonies, probably derived from a single infected droplet. It appears then that under the most severe conditions that can well be devised the bacteria in infected liquids reach the air adjacent only rarely and in small numbers.

VIII. SEWAGE BACTERIA IN THE AIR OF PLUMBING PIPES UNDER NATURAL CONDITIONS.

The laboratory experiments detailed above appeared to show that although bacteria can be thrown into the air by splashing and bubbling liquids the amount of infection produced in this way is slight, even under extreme conditions. The important thing, however, is to determine what occurs in house drains and branch connections actually in use. Experiments with artificial inoculations of rich bacterial cultures must always give a somewhat distorted view of the possibilities, and no work which is not quantitative can give any idea of the practical importance of the problem.

With the cooperation of Mr. David Craig of the Sanitary Committee of the Master Plumber's Association, I therefore undertook an examination of the drain air of plumbing systems of different sorts in various Boston buildings, with a view to seeing how abundant sewage bacteria were as a matter of actual fact. Nineteen plumbing systems were selected in nineteen different buildings of various sorts, hospitals, educational institutions, tenements, public buildings, a hotel, an office building, etc. At twenty points on these nineteen systems the pipes were tapped for the examination of the air and from each point ten liters of air were collected for examination. The sampling points were selected to give as wide a range of conditions as possible. Some were on main stacks of soil pipe, some on the main stack prolonged above the roof, one on a vent pipe, several on the main house drain or on clean-outs connected closely with it. Each series of ten liter-samples was collected at intervals in a period of an hour and a half. Thus in all 200 liters of drain air were examined, representing a wide variety of conditions in nineteen different plumbing systems, and forming a fairly representative idea of the composition of house drain air.*

The general method adopted was that described as the Culture Bottle Method in Section V, above. One liter of air was drawn into two liter-and-a-half bottles arranged in tandem and the bacteria in the air were allowed to settle out and then cultivated. My object was not to determine the total number of bacteria but to isolate specific forms. I therefore replaced gelatin in the bottom of the Culture Bottles by a solution of dextrose broth, which forms the most suitable and delicate medium for the detection of sewage bacteria, of the *B. coli* and the *Streptococcus* types. The bottles were incubated at body temperature, 37 degrees, centigrade for three days. As soon as growth appeared in any bottle sub-cultures were made on litmus-lactose-ager and if any acid colonies appeared they were examined further. The *Streptococcus* type was defined as including all acid forming streptococci and the *B. coli* type was recognized by gas formation in dextrose broth, coagulation of milk, reduction of nitrates, formation of indol and non-liquefaction of gelatin.

The first test of an actual plumbing system, Series A., was made on May 27, 1908, in the Henry L. Pierce Building of the Massachusetts Institute of Technology. The sampling point

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* Thanks are due to Mr. A. F. Stevenson for assistance in the conduct of these experiments.

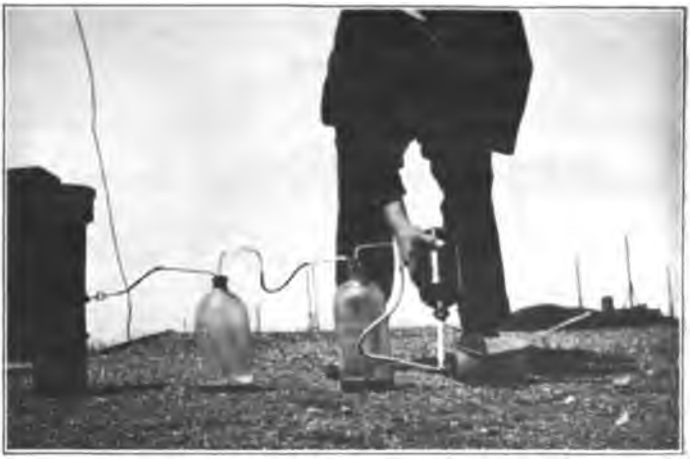

FIGURE VI.
Photograph of Apparatus used in sampling Air of Plumbing Systems in actual use

was on the main stack of soil pipe in the basement. Above there were fixtures on four floors, two water closets and two urinals on each. The plumbing was about ten years old. The number of persons using the building is about 150.

In this first test the inlet pipe of the first Culture Bottle was passed through the 3-4 in. hole drilled in the pipe directly into its interior. The hole was situated in a branch clean-out a few inches from the main stack and it soon appeared that the liquid in the pipe was running over the walls of the clean-out and dropping into the end of the collecting tube. From three of the bottles *B. coli* was isolated, but the possibility that direct infection had taken place by the trickling of a thin stream of sewage along the collecting tube led me to discard these results.

In all further work precautions were taken to prevent accidents of this sort. Short pieces of glass tubing were prepared with a bulb about one inch in diameter blown in the middle of each. One end of the tube was inserted into a rubber stopper which fitted the hole drilled in the plumbing pipe and the Culture Bottle was thus protected from direct liquid infection, unless the bulb became so full as to overflow. When this occurred, as it did in a few cases, it could easily be observed and the test excluded. The arrangement of the apparatus and the method of taking samples are shown in Figure VI.

The second series of tests, Series B, was made in the Rogers Building of the Massachusetts Institute of Technology, on May 28, 1908. The plumbing here was old, the main stacks having been installed for 40 years. Some 300 people use the building during the day time. The sampling point was on the waste from a line of four urinals on the first floor, a few feet from the main stack and in direct connection with it. Above, on the main stack, were two water closets and three urinals, and below in the basement one water-closet and three urinals. Two of the ten liters of air collected at this point showed growth in the Culture Bottles, but in neither case were intestinal bacteria present.

Series C was carried out on June 1 in the Henry L. Pierce Building of the Institute at the same point described under Series A, with the single difference that the bulb described above was placed between the pipe and the Culture Bottle to prevent direct contamination. The importance of this precaution and the propriety of excluding Series A from consideration were shown by the fact that in six of the ten tests an appreciable amount of sewage collected in the bulb. None reached the bottles however. Two out of the ten showed growth but neither contained colon bacilli or sewage streptococci.

The tests of Series D were made on June 1, in the afternoon, in Ward E of the Boston City Hospital. The sampling point was on a sink drain in the cellar a few feet distant from its entrance into the main drain. On the stack entering the main drain were two water closets, a urinal, two baths and several slop hoppers and sinks. The plumbing is about six years old. Of the ten liters examined, only one contained bacteria capable of growth at 37 degrees, and these were not sewage forms.

Series E was carried out on June 2 at the Sanitary Research Laboratory of the Massachusetts Institute of Technology on Albany street. There there is a small two-story laboratory building with a single water closet and several sinks, used by four persons. Samples were collected from the soil pipe above the entrance of the drains from the fixtures. Two liters out of ten showed growth at 37 degrees, but no intestinal forms.

Series F was again at the City Hospital on the system serving wards W and X. Samples were taken from a sink drain about two feet from the main drain in the basement. On each of the two floors above were two water closets, a sink, a slop hopper and a urinal. The system was about 12 years old and the Ward contains 28 beds. When the third sample was collected at 10:20 and the ninth at 10:55, the sink above the sampling point was discharged. In each case liquid collected in the bulb, but in neither did it pass over into the Culture Bottle. In the case of the third sample, however, *B. coli* was isolated from both the first and the second Culture Bottle. Here was the first case in which sewage bacteria were present in the drain air; and in this instance they were found in immediate contact with actively splashing liquid.

The system chosen for Series G was in the Nurses' Home of the City Hospital. The plumbing here is 22 years old and the population of the house about sixty. The sampling point was on the main stack of soil pipe on the second floor of the building. There were four water closets and four bowls above and the same below. Leaking fixtures of some sort produced a steady flow of liquid down the pipe during the whole course of the experiments, and flushes occurred at frequent intervals. Water collected in the bulb in every case but two. In collecting the fourth, eighth and tenth samples, the bulb overflowed into the Culture Bottle. All three of these samples showed *B. coli.* In addition the sewage *Streptococus* was isolated from the first sample. This is the second instance in which sewage bacteria were present in the drain air; in this case as in the one previously cited there was active splashing of liquid at the point of collection.

The tests of Series H were made on the afternoon of June 5 at the Technology Club on Newbury street. Samples were collected from the main soil pipe. Two water closets and two baths were above and two water closets and two urinals below. Growth occurred in three out of ten samples, but no intestinal forms were found.

The samples for Series I were taken on June 6, from the plumbing system in a private residence in Newbury street. The plumbing is about twenty years old and is used by six or eight persons. The sampling point was in the basement on the vent pipe from the water closet, of course connected above with the rest of the vent pipes of the system. In such a position the contact with sewage material was somewhat remote, but it seemed of interest to include one such case at least in the investigation since so much house plumbing is similarly circumstanced. Two of the ten samples showed growth, but no intestinal bacteria were found.

Series J was carried out June 8 in the Walker Building of the Massachusetts Institute of Technology. The sampling point was on the main stack of soil pipe with three urinals and various sinks above and two water closets and three urinals below. The plumbing is about 25 years old. Chemicals discharged into the stack from sinks in the Chemical Laboratories might produce some disinfectant action in this system. Water collected in the bulb three times and once passed over into the bottle. In one case growth occurred, but no intestinal forms were found.

Series K was carried out on June 10, in Ward P of the City Hospital. This is old plumbing, in place for 34 years, and like the other wards this one is occupied by 28 persons, besides nurses and attendants. On the main stack are two water closets, one urinal, one slop hopper and one bath. Samples were collected from a clean-out at the extreme end of the house drain close to the entrance of a sink drain, but some distance from the main soil pipe. The sink was flushed out during the taking of the fifth sample. This and one other sample showed growth, but no intestinal forms.

The tests of Series L were made at the Hotel Lenox on June 11. The plumbing here is eight years old and consists of a series of stacks each passing straight up through the ten floors of the hotel and receiving the wastes from a water closet, a bath and a sink on each floor. Samples were collected from a clean-out at the foot of the main stack in the basement. Three samples showed growth, but none sewage bacteria.

In Series M, (June 11, afternoon) the air of another stack at the Lenox of exactly similar construction was examined. In this case the samples were collected from the stack just above the roof. The top of the stack in tests of this sort was left uncovered and there was a strong current of air passing upward by the sampling point. Six of the ten samples showed growth, but no sewage bacteria were found. It is interesting to note that of the nine samples in the two Lenox series which showed growth, seven were molds, a phenomenon not observed in other cases.

Series N was carried out at the City Hall on June 12. The stack tested was a four-inch soil pipe passing through the roof near the northeast corner of the building; and the sampling point was just above the roof. I was unable to find out just which fixtures were connected with this stack. Two bottles showed growth, but no sewage forms.

The next series of tests, Series O, was made in the Old Court House, behind City Hall, on June 13. The system examined had been put in for about two years. It included three water closets and two bowls on one line and seven water closets, seven bowls, and four urinals on another. The sampling point chosen was a clean-out on the main drain below the first stack and above the second. Three samples showed growth, but none contained *B. coli.*

The tests of Series P were made at the Ames Building, (offices) on June 15. The sampling point was on a main six inch soil pipe just above its passage through the roof. The stack has been in use for 17 years and receives the drains from ten water closets, besides sinks and hoppers. Four of the ten samples showed growth, but no intestinal forms.

The next four series of tests were made in three tenement houses on Border street, East Boston. The plan of all three systems was the same. A four-inch house drain, running the length of the cellar, received at each end a rain water leader, and in the middle a stack of soil pipe. On the stack in each case were three water closets and three sinks, used by 15 to 20 people. The plumbing is about 12 years old.

The tests of Series Q and R were made on the main stacks of tenement houses A and B just above the roof on June 18 and 19. In Series Q two samples showed growth, in Series R none. No sewage forms were found.

Series S proved of great interest. The samples were taken on June 19 from the main house drain in the part of the pipe intended for carrying rain water from the front leader, but only about ten inches from the foot of the soil pipe. The location was thus well within reach of splashing from the liquid striking the bottom of the stack. While the first, sixth and ninth samples were being collected there were flushes in the soil pipe. From the first and ninth samples *B. coli* was isolated. There was no collection of water in the bulb in either case. Clearly the splashing of the sewage in the soil pipe produced a fine spray which was carried by the air into the Culture Bottles. It is almost of equal significance however to note that the second sample and the tenth showed no sewage forms. The first flush occurred at 11:40. At 11:45 the sewage bacteria had disappeared from the air one foot away. The second flush occurred at 12:50; and the sewage forms were gone at 1.

The tests of Series T were made in tenement house C, on June 20. A hole was drilled for sampling in the house drain just above the soil pipe as in Series S. The drain had sagged somewhat, however, and the portion of the pipe formed, as it appeared, a pocket full of stagnant and septic sewage. This should be an admirable preserve of disease germs according to the older view point. I therefore had another hole drilled further back along the house drain, twenty feet from the soil pipe and about five feet from the backed-up sewage. Two of the ten samples of air from this point showed growth but no sewage bacteria.

Series U was carried out at the Engineering A Building of the Massachusetts Institute of Technology, on June 22. Samples were taken from the main soil pipe above the roof. The system is about 20 years old and includes six water closets, twelve urinals and various sinks. No growth occurred in any of the Culture Bottles.

The general results of all the experiments are summarized in Table X below. Growth in the Culture Bottles is indicated by a minus sign. The presence of intestinal forms, (*B. coli* or sewage streptococci) is indicated by a plus sign, and when direct infection by the running over of liquid occurred the plus sign is doubled.

TABLE X

BACTERIA IN THE AIR OF DRAIN PIPES UNDER NATURAL CONDITIONS. 200 ONE LITER SAMPLES

— Bacteria present. + Sewage Bacteria present in the air. ++ Sewage Bacteria introduced by direct liquid contamination.

Sample	Series	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1							+									—			+	—	
2							—		—				—		—				—		
3						+		—			—		—	—			—				
4							++			—			—								
5									—			—			—	—	—				
6			—	—	—		—	—					—	—		—					
7		—	—		—							—				—					
8		—					++														
9								—					—		—						
10								—					—		—				+	—	
							++				—	—	—			—					

Out of 200 one-liter samples of drain air 152 contained no bacteria capable of growing at 37 degrees. 41 more showed none of the organisms recognized as characteristic of sewage. In three cases direct liquid infection took place, introducing colon bacilli. In four other cases, only, out of the 200, were sewage bacteria isolated from the air of the house drains studied. In every one of those four cases there was vigorous splashing of sewage within a few inches of the sampling point and at the moment the sample was taken. At points further removed from splashing, and at the points where splashing had occurred ten minutes before, no sewage bacteria were found. In the whole series of 200 liters of air collected from the most diverse locations on nineteen different plumbing systems, not a single sewage organism was found except where the air was exposed to immediate local infection by fine particles of spray.

IX. SUMMARY OF PREVIOUS SECTIONS AND CONCLUSIONS AS TO THE ROLE OF SEWER AND DRAIN AIR IN THE SPREAD OF BACTERIAL INFECTIONS.

The idea of the connection between sewer gas and disease dates back to the days when the cause of the infectious maladies was still unknown. Mysterious miasmatic influences were naturally enough supposed to accompany the foul odors of decomposing organic matter. When it was proved that the contagious and infectious diseases are due to the presence of microscopic plant and animal parasites, the case against sewer gas seemed less convincing.

Nägeli and many other bacteriologists showed that under ordinary conditions germs adhere strongly to moist surfaces and are not easily given off from liquids into the adjacent air. Sir Edward Frankland in England and Raphael Pumpelly in this country carried out experiments which indicated that chemicals in solution, and bacteria in suspension, might be thrown into the air from liquids by the bursting of bubbles. On this contingency the possible danger of sewer gas infection still might rest.

Actual examinations of the air in sewers, however, by Miquel in France, Petri in Germany and Carnelley and Haldane, Robertson and Laws and Andrewes in England showed that sewer air as a matter of fact contains very small numbers of bacteria and those of types common in street air rather than in sewage. Uffelmann found the same condition in the air of a house drainage system. Carnelley and Haldane and Laws and Andrewes isolated sewage bacteria in the immediate vicinity of points where active splashing occurred. As in the experimental studies of Frankland, Pumpelly and Dr. Abbott of Philadelphia there was clearly a possibility of air infection where spray was produced by some mechanical method. On the whole, however, the air of drains and sewers seemed to be of high bacterial purity and all the observers who studied normal conditions in actual sewers concluded that the danger of bacterial infection from sewer air was remote.

These results, with the absence of any reliable evidence from the study of epidemics in favor of the transmission of germs by sewer air, has led sanitarians in Germany and the United States to agree with practical unanimity that the danger of such transmission may be disregarded. In England, on the other hand, a large number, probably a majority, of sanitary experts have failed to be convinced, and have clung to the opinion that under some conditions the carriage of disease bacteria by sewer air is a practical possibility.

A little over a year ago, at the request of the National Association of Master Plumbers, I made some experiments on this problem, upon which no practical investigations had been conducted for over ten years. I used an experimental stack of four-inch soil pipe, fifteen feet in height, with a running trap at the bottom and an exhaust fan, for drawing up a strong current of air, at the top. Sewage was placed in the trap, sealing it partially or completely, or resting in the bottom without sealing it. Air was drawn over the sewage and wetted surfaces of the pipe or was bubbled through the sealed trap and the air was examined at various points in the stack above. When the air current was strong, an increase was noted in the bacterial content of the pipe air; but the increase was not striking even at high velocities and was entirely wanting with air currents of less extreme force. Only three of the characteristic bacteria of sewage were isolated from the air in the whole series of experiments. As a result of this investigation I reported that the danger of bacterial infection from drain air was but slight.

At about the same time a series of experiments on sewer air was reported to the Royal Society of London by Major W. H. Horrocks of the English Army Medical Corps. His results seemed at first sight to warrant widely different conclusions from those drawn by other observers; and it seemed necessary to re-examine the whole question with the greatest care.

Major Horrock's general method consisted in the artificial infection of the lower part of natural and experimental drainage systems with a peculiar bacterium, the *Bacillus prodigiosus,* which is not normally found in the air. He then exposed small open dishes of nutritive media, (Petri plates) in the upper part of the systems. Germs carried up in the air fell on the plates, grew and developed into visible colonies, and among these colonies he identified the particular form, *B. prodigiosus,* introduced in the liquid at the bottom. By this process he detected his test organism in a pipe 9 feet above an experimental running trap into which it had been introduced, and in the air of a catch basin of the town into which he had poured it. Similar results were obtained when the lower sections of his experimental pipe system were wetted with a culture of the *B. prodigiosus* and then dried. The dried germs were apparently detached, carried up by the air and deposited on the plates. In another series of experiments sewage, infected with the typhoid bacillus or with *B. prodigiosus,* was allowed to flow, quietly and without splashing, through a horizontal pipe to which a vertical pipe was connected at an intermediate point. Plates exposed in the vertical pipe showed colonies of the specific bacteria introduced below, even at a height of eleven feet, nine inches above the liquid. Again, emulsions of *B. prodigiosus* were flushed from the closets of drainage systems in actual use and the germs thus introduced were found in all parts of the systems in open connection therewith, even at a height of fifty feet above the traps. Major Horrocks, by the same method of exposing Petri plates, found *Bacillus coli,* the characteristic organism of sewage, in a house drain and in the main sewer of the town. Finally he passed the feces of a typhoid patient suspended in water through a half-S-trap and found the typhoid organism on plates in a vertical pipe above it at a height of 3 feet, six inches above the liquid.

Major Horrocks' report, and a still more recent series of confirmatory experiments by Dr. F. W. Andrewes of London, naturally excited the deepest interest among sanitarians. In many quarters the old suspicions of sewer air were revived in almost their full force.

The Journal of the American Medical Association for example said in commenting upon Horrocks' work: "We may still have to look to sewer emanations as the occasional cause of mysterious outbreaks of disease." Other sanitarians maintained a more conservative attitude, and waited further evidence before abandoning their previous conclusions. The matter stood about as follows: On the one hand Horrocks had shown that specific bacteria, present in traps and drains, could get into the air above by splashing, by the bursting of bubbles and even in some experiments from the surface of liquids apparently in quiet motion; he detected such bacteria by the plate method in the air of ventilating pipes at considerable distances, (once at fifty feet) above the infected liquid. On the other hand, Miquel Petri, Uffelmann, Carnelley and Haldane, Laws and Andrewes and others had shown that the number of bacteria actually present in the air of sewers and house drains is extremely small and that those present are generally air forms and not sewage forms. Furthermore reliable evidence of the spread of infectious disease by sewer air is wholly lacking. The inconsistency of the two sorts of evidence required explanation; and, after presenting the facts to the Sanitary Committee, of the National Association of Master Plumbers, I was commissioned by them to attempt the clearing up of the apparent contradiction.

I first attempted to repeat as closely as possible one of Horrocks' simpler experiments. I examined the air of a boat chamber on one of the main sewers of the city of Boston, as Horrocks had done in the sewers of Gibraltar. I found colon bacilli, the characteristic sewage organism, on my plates in many experiments; but their number was least nearest the sewage, greater nearer the street, and greatest in the street air itself. It was clear that they came from street dust infected by horse dung, etc., and not from the sewage at all. I then constructed an experimental pipe system, such as Horrocks used, consisting of a half-S trap of six-inch tile drain to which an eight-foot vertical stack of the same pipe was connected. A rich emulsion of *B. prodigiosus* culture, or of *B. coli* culture, in soapy water was poured through the trap and Petri dishes of nutrient gelatin or agar were suspended at various points in the pipe above. Control plates were also exposed at various points in the laboratory outside. Six out of 28 plates exposed in the pipe over the *B. coli* emulsion showed colonies of this germ, 14 colonies in all. Eight out of 24 plates exposed in the pipe over liquid infected with *B. prodigiosus* showed this organism, 17 colonies in all. The general effect of these experiments was therefore to confirm the results of Major Horrocks. My tests, like his, showed that specific bacteria are discharged into the air from the surface of foaming infected liquids and may be carried up in connecting pipes for considerable distances. Furthermore I found that the velocity of an air current capable of transporting bacteria in the form in which they are sprayed into the air from an atomizer is very low indeed.

Granting then that infection of the air above sewage may take place, how can the results of actual examinations of sewer air be explained? The idea suggested itself at once that the whole question might be a quantitative one. It might be possible that under extreme conditions sewage bacteria get into the air but that the number discharged is so small under normal conditions that it does not appreciably affect the composition of the air of the sewer as a whole.

I next therefore attempted to investigate the question from this standpoint; and made first a careful examination of the best available quantitative methods. Horrocks' procedure of exposing open dishes of nutrient media to the air is of course not quantitative at all since the bacteria which happen to fall on the plate are not related to any particular volume of air. The method adopted by most recent observers, and the one which I used in the experiments reported a year ago, involves the straining out of the bacteria in a measured volume of air by drawing it through a sand filter. The bacteria are then washed out from the sand in sterile water and enumerated by the ordinary cultivation methods. During my work this year I developed a new method in which a measured volume of air is drawn into two large Culture Bottles and the bacteria are allowed to settle out and form colonies on nutrient media in the bottom of the bottles. This method, although cumbrous, avoids all danger of losing bacteria by drawing them through the sand and was used in all my later work. A careful series of comparative tests showed, however, that the sand method used in other investigations is essentially accurate and earlier results may be accepted as correct in their general conclusions.

By the use of the Culture Bottle Method I next attempted to control Major Horrocks' results from the quantitative standpoint. I prepared a rich emulsion of *B. prodigiosus*, containing hundreds of millions of bacteria per liter, made it foam freely by beating it up with soap, and poured it into a large glass bottle or into an open dish. The air in the bottle, or the air of the laboratory over the open dish, was examined by the Culture Bottle Method. Out of thirty liters of air examined, five only contained *B. prodigiosus*. In one liter, three were found, and in the other four, one each. Clearly the bacterial infection of the air produced by very vigorous foaming was but slight.

In these experiments there was but little splashing of the infected liquids; the bursting of bubbles from the foaming surface was the only source of air infection. I next imitated natural conditions more closely. Through the kindness of Mr. Craig I had an ordinary porcelain water-closet bowl set directly on a four-inch cast-iron S-trap, having a clean-out hole at its crown. The S-trap was connected at its lower end with an ordinary four-inch running trap. A rich, soapy emulsion of *B. prodigiosus* was poured rapidly into the water-closet bowl so as to rush down through the two traps, foaming and splashing as it went. Samples of air were collected from the clean-out at the crown of the upper trap and from the upper opening of the lower running trap, a few inches only from the foaming surface of the liquid. Everything was as favorable as possible for the discharge of bacteria into the air. Yet, out of 44 liters of air examined, 43 contained no *B. prodigiosus*. One liter showed a group of eleven colonies apparently derived from a single infected droplet. It must be remembered that in these experiments, I used liquids artificially infected with large numbers of specific bacteria and caused to foam artificially by beating them up with a considerable addition of soap. Vigorous splashing was added to foaming in the last series of tests. Under these extreme conditions, as in Major Horrocks' experiments, the specific bacteria present could be detected in the air; yet the actual number present even here was extremely small.

These experiments seemed to offer a reasonable explanation of the difference between Major Horrocks' results and those of other observers. Bacterial infection of the air from foaming liquids may take place. Horrocks, using for the most part artificially prepared emulsions and ignoring the quantitative aspect of the case, naturally obtained positive results. When the question is approached numerically, however, the amount of air infection, even under extreme conditions, is so slight that one would scarcely expect the general air of sewers and house drains to be appreciably affected under normal conditions.

The final test of experimental conclusions of this sort must always be made by an appeal to existing conditions under normal circumstances of actual use. The numerous investigations cited above have shown that the air of street sewers is indeed singularly free from bacteria. The air of house drainage systems might, however, be supposed to be worse than that of the street sewers; and with regard to their bacterial condition only the single report of Uffelmann appears to be available. As a crucial test, I therefore determined to carry out a sufficient number of examinations of house drain air to gain a fair idea of its bacterial composition. With the cordial co-operation of Mr. Craig, I have been able to complete this work and to obtain results which seem to be conclusive.

I studied nineteen different plumbing systems, five in buildings of the Massachusetts Institute of Technology, four in the wards of the Boston City Hospital, three in a block of East Boston tenements, two at the Boston City Hall, two at the Hotel Lenox and one each in the Ames Building, in the Technology Club, and in a private residence on Newbury Street. The plumbing pipes were tapped at various representative points, on the main stack in the lower part of the building, on the projection of the main stack above the roof, on clean-outs on the main house drain, on wastes from fixtures and dead ends in connection with the house drain, and in one case on the ventilation system at some distance from the main stack. From each of twenty points selected, ten liters of air were drawn off and examined for the characteristic bacteria of sewage, the colon bacillus and the sewage streptococcus.

In all, 200 liter samples of air were examined. Three samples were lost from the fact that the liquid sewage in the plumbing pipe ran into the collecting tube and over into the Culture Bottle, directly contaminating it with liquid. There remained then 197 tests. Of these 193 showed no sewage bacteria present. In the remaining four cases, sewage organisms were found, the colon bacillus three times and the streptococcus once. In each one of these four cases there was a discharge of sewage in the pipe at the point of examination, and at the moment the sample was taken so that spray was actually splashing in the air. In each of the four cases a sample of air from the same point ten minutes later showed no sewage forms present. In not a single case out of the 200 were sewage bacteria present in a liter of house drain air unless there was mechanical splashing at the point, and at the moment, of examination.

In general my results confirm the results of Horrocks in so far as they show that specific bacteria may be ejected from liquids into the air above. My tests of house drain air, like those of Carnelley and Haldane and Laws and Andrewes on sewer air, indicate that mechanical splashing may produce a local infection of the air in immediate contact with the spray. Such an infection does not, however, extend for any distance or persist for more than a minute or so. I found the general air of house drainage systems singularly free from bacterial life. Out of 200 liters examined, only 48 contained any organisms capable of development at 37°. Sewage bacteria were found in the air of the house drains only four times out of 200 liters, and then in the presence of mechanical spraying of sewage at the point of collection. The general air of the house drainage system, aside from this local infection, was, as far as examined, free from sewage organisms. These results accord well with those obtained by Miquel, Petri, Carnelley and Haldane and Laws and Andrewes in street sewers, and with those reported by Uffelmann for drain air.

The experiments of Major Horrocks, rightly interpreted, in no way contradict this general consensus of opinion. He demonstrated a possibility; by using, for the most part, artificially infected, and foaming emulsions, and by ignoring all quantitative considerations. We must deal, however, in sanitation, not with theoretical possibilities, but with probabilities, measured as closely as possible in regard to their practical importance. I have found in my experiments that even under the most extreme conditions the number of bacteria which get into the air from an infected liquid is small. I have found by the examination of a series of plumbing systems in actual use that intestinal bacteria could only be isolated four times out of 200 liters, and then only at points of direct local infection from splashing.

In a surface water of good quality, like that of New York City, the colon bacillus can almost invariably be isolated from ten cubic centimeters. This means a slight degree of intestinal pollution, but experience has shown that the chance of infection from such a water is but slight; and we drink it without serious alarm. If one were to breathe for 24 hours the undiluted air of a house drainage system, at any point not immediately infected by mechanical splashing, it appears that less than fifty intestinal bacteria would be taken in; for the daily consumption of air is about 10,000 liters, and in 200 liters I obtained negative results from air of this sort. In drinking New York water, twice as many colon bacilli are ingested every day, for 1000 cubic centimeters is a small amount for daily consumption. So there would be less danger of contracting disease from continually breathing the air of a vent pipe, or of a soil pipe, except where liquid is actually splashing, than from drinking New York water.

There is a possibility of course that the gaseous emanations from decomposing organic matter may exert a pre-disposing influence which makes the body succumb more easily to specific germs, introduced in other ways. Many have held that in this way sewer gas might indirectly promote disease. This view, supported mainly by the experiments of Alessi, well deserves further study; but I have not dealt with it in the present investigation. I believe, however, that my results, in the light of all previous evidence, warrant the conclusion that the chance of direct bacterial infection through the air of drains and sewers is so slight as to be practically negligible.

June, 1908.

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 229

THE DISINFECTION OF SEWAGE AND SEWAGE FILTER EFFLUENTS

WITH A CHAPTER ON THE

PUTRESCIBILITY AND STABILITY OF SEWAGE EFFLUENTS

BY

EARLE BERNARD PHELPS

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ΓHE DISINFECTION OF SEWAGE AND SEWAGE FILTER EFFLUENTS.

By Earle Bernard Phelps.

INTRODUCTION.

The investigations on which this report is based were conducted by E. B. Phelps at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology at Boston, Mass., and, in collaboration with Mr. Phelps, by Francis E. Daniels at the sewage-disposal works at Red Bank, N. J., and by Ezra B. Whitman at the Walbrook Testing Plant at Baltimore, Md., under cooperative agreements with the Massachusetts Institute of Technology, the State Sewerage Commission of New Jersey, and the city Sewerage Commission of Baltimore.

SEWAGE PURIFICATION.

PURIFYING AGENTS.

The essential agents of sewage purification are provided and employed by nature. The slow action of the soil bacteria, aided by atmospheric oxygen, eventually converts into harmless mineral ingredients all organic matter that comes within its sphere of activity, the process being analogous to that of combustion. Sewage purification as practiced to-day is but the intensive application of these natural processes under controllable conditions. The improvements that have been made in methods of treating sewage have not involved the discovery or application of new principles, but have merely increased the working efficiency of the natural bacterial agencies. The constant aim of the experimenters has been to increase the rate at which sewage can be treated on a given area of land. From the old-time sewage irrigation field, with its maximum capacity of possibly 10,000 gallons an acre in twenty-four hours, to the present-day trickling filter capable of dealing with two or three million gallons an acre a day, the march of improvement has been steady and continuous. The amount of sewage that can be purified on an acre of filtering area has been increased two or three hundred fold, and investigators are working toward a still greater increase.

It must be admitted that the significance of the word "purify" has also undergone a radical change. The effluents are no longer pure ground water. The liquid flowing from a modern trickling filter looks to the untrained eye like the original sewage. The organic matter of the sewage is no longer "burned up" to harmless mineral matter; indeed, there is almost as much organic matter in the effluent as in the raw sewage, and sometimes more. What change then has taken place to justify the use of the term "purified?" The answer lies in the fact that the organic matter has been changed but not removed. To carry out the simile, the organic matter, though not burned, has been charred or partly oxidized, and this charring process has been sufficient to rob it of its putrescibility or foulness. In other words, its chemical composition has been so altered that it is no longer capable of undergoing rapid putrefactive decomposition.

On first consideration it appears inconceivable that the chief object of sewage disposal—prevention of the fouling of streams—could be attained by such subtle changes in the nature of the organic matter. Nevertheless, effluents containing comparatively large amounts of organic matter may be discharged into streams without fear of causing nuisances if the organic matter is nonputrescible and if conditions preclude immediate sedimentation. The work of purification proceeds in the stream as it does in the soil until the oxidation, or combustion, is complete, oxygen for that purpose being sufficiently abundant in a reasonably clean stream. On the other hand, too much crude sewage added to water first robs it of all its available oxygen, then, in the anaërobic condition thus established, kills the beneficent oxidizing bacteria and transforms the stream practically to an open sewer. It is apparent, therefore, that purification of sewage has come to mean primarily the removal of its tendency to putrefy and not the total oxidation and removal of all its organic matter.

FATE OF BACTERIA IN SEWAGE FILTRATION.

In the older and more perfect methods of sewage purification the bacteria of the sewage with the other organic matter were destroyed by the straining action of the soil and the oxidizing action of the normal soil bacteria; but a modern filter of coarse stones neither strains the material nor affords opportunity for vigorous oxidation. Much of the original organic matter passes through such a filter, having undergone changes so slight as almost to defy detection by ordinary chemical means. It is reasonable, therefore, to inquire as to the fate of the sewage bacteria and particularly as to the pathogens, or disease-producing microbes. The data on this point are somewhat flicting. The question was raised in 1893 in connection with the septic tank at Exeter, England. The fear was expressed that nogenic germs might even multiply in the tank, as other forms acteria are known to do. Sims Woodhead conducted an investi-on as a result of which he concluded that no organisms capable etting up morbid changes in animals after inoculation came from tank. Pickard introduced an emulsion of typhoid bacilli into Exeter tank and observed a slow diminution in number. It is ortant to note, however, that even after fourteen days 1 per t of the original number was still alive. Pickard also reported emoval of over 90 per cent of the typhoid organisms introduced a contact filter. Rideal, on examining the effluents of three tt-Moncrieff filters at Caterham, England, found reductions in *cillus coli* ranging from 95 per cent to 98.5 per cent. He made following statement before the Royal Sewage Commission:[a] atisfactory evidence in most of the systems is now available from ich I think we are justified in concluding that even if towns on a er like the Thames adopted bacterial schemes the pathogenicity the London water supply would not be adversely affected thereby."

On the other hand, there is some evidence that the pathogenic prop-ies of sewage are not materially altered in its passage through a arse-grained filter. Alfred MacConkey[b] made a series of tests on the longevity of *B. typhi* in various waters. Samples of the uid under examination were inoculated with large numbers of phoid bacilli and were kept under observation. In one experi-ent the organism was isolated from sewage thirteen days after oculation. In a second set of two tests it was not found after fif-en and after seventeen days. In two contact-bed effluents it was und after fifteen and seventeen days, respectively, while in two her contact-bed effluents it did not survive beyond the sixth day. acConkey concluded that the numbers of typhoid organisms reach-g a filter are ordinarily so small that there is but slight possibility their passing through, but "if from any cause they arrive to the nks in such large numbers as the *B. coli*, then certainly they might ppear in the effluent just as the *B. coli* does." In interpreting ich results due allowance must be made for the fact that the isola-on and identification of the typhoid bacillus under such conditions extremely difficult and that failure to detect the organism carries uch less experimental weight than a positive result.

Houston,[c] in a careful investigation of the subject for the Royal ewage Commission, found that the effluents from septic tanks, con-act beds, and trickling-filter beds contained enormous numbers of bacteria. In some of the tests the per cent reduction in the effluents as compared with the raw sewage was striking; but as it was necessary to judge an effluent by its actual condition, and as the number of micro organisms still remaining was almost always very large, he concluded that per cent purification is of minor importance. In not a few of the tests the bacteria were practically as numerous in the effluent as in the raw sewage. The relative abundance of the different kinds of bacteria appeared to be much the same in the effluents as in the crude sewage. Of undesirable bacteria, such as *B. coli*, proteus-like germs, spores of *B. enteritidis sporogenes*, and streptococci, the effluents contained nearly as many as the crude sewage. The reduction in numbers of these objectionable bacteria was apparently not marked enough to be of consequence from the point of view of the epidemiologist. No definite proof was found that the effluents from bacterial beds were conspicuously safer than crude sewage in their possible relation to disease. Attention was especially called to the presence of streptococci in the effluent. Houston contends that if it be true that streptococci are more delicate germs than the typhoid bacillus, their presence in large numbers in the effluent indicates the possibility or probability that the typhoid bacillus also survives under similar conditions—a view that leads to the inference that the biological processes at work are not strongly inimical, if hostile at all, to the vitality of pathogenic germs. Experiments with *B. sporogenes*, a spore-forming organism, have shown that it passes through filters in almost undiminished numbers.

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[a] Interim Rept. Royal Sewage Commission, 1901, Question No. 4148, p. 251.

[b] Second Rept. Royal Sewage Commission, 1902, p. 62.

[c] Houston, A. C., Second Rept. Royal Sewage Commission, 1902, p. 26.

Besides the facts already mentioned, little information is available which bears directly on the fate of the pathogens, and particularly of the typhoid organism, in sewage purification. It is therefore necessary to examine the available indirect evidence. By studying the removal of certain specific organisms that are easily detected and certain well-defined groups of organisms existing in sewage, the probability of the elimination of the typhoid organism can be determined. In the absence of further data it must be assumed for the sake of safety that the elimination of the typhoid bacillus is not materially greater than that of the other species and groups that may be studied. During the summer of 1904 there were operated at the sewage experiment station four septic tanks running at storage periods of from twelve to forty-eight hours, nine contact beds differing in material, depth, and rate, three trickling filters, and three sand filters, one of each set being run with crude sewage and two kinds of septic effluents, respectively. The results of bacterial counts are shown in Table 1, in which the numbers are averages of all results obtained with one kind of filter.[a]

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[a] Winslow, C.-E. A., The number of bacteria in sewage and sewage effluents: Jour. Infect. Dis., vol. 1, Suppl. 1, 1905, p. 209.

TABLE 1.—*Bacteria in sewage and in effluents of sewage filters at Boston in 1904.*

[Winslow.]

Source of sample.	Number of examinations.	Bacteria per cubic centimeter.					
		Lactose gelatin at 20° C.			Lactose agar at 37° C.		Anaërobic agar.
		Liquefiers.	Acid formers.	Total.	Acid formers.	Total.	
Sewage	56	365,000	1,670,000	5,430,000	1,670,000	3,760,000	2,440,000
Septic effluent	56	162,000	495,000	1,750,000	650,000	1,040,000	930,000
Contact filters	140	60,000	270,000	1,060,000	290,000	570,000	440,000
Trickling filters	18	134,000	114,000	451,000	284,000	1,170,000	200,000
Sand filters	15	500	1,360	9,160	11,400	43,600	1,200

The septic tank and two trickling filters in operation at the same station during the summer of 1906 gave the average results recorded in Table 2, showing that less than one-half of the bacteria growing at 37° C. were removed by filtration, and that the reduction in the number of colon bacilli was practically in the same proportion.

TABLE 2.—*Bacteria in sewage, septic effluent, and trickling-filter effluents at Boston in 1906.*

Source of sample.	Bacteria per cubic centimeter; lactose agar at 37° C.	B. coli; positive[a] tests in one-millionth of a cubic centimeter.
		Per cent.
Sewage	1,300,000	65
Trickling filter receiving sewage	750,000	35
Septic effluent	1,650,000	66
Trickling filter receiving septic effluent	750,000	35

[a] The bile broth presumptive test recommended by D. D. Jackson was employed.

Johnson,[a] in his experiments at Columbus, found a reduction in the total number of bacteria ranging from 33 per cent to 60 per cent in primary-contact filters, and a removal of about 39 per cent of the remainder in secondary-contact filters, and from 30 per cent to 80 per cent in trickling filters, depending largely on the depth of the filter. Subsequent sedimentation increased this removal to 87 per cent. Thumm and Pritzkow,[b] at Berlin, report a reduction in the number of bacteria from 17,000,000 in the sewage to 6,000,000 in the effluent of a double-contact filter. At La Madelein, France, Calmette[c] found 5,000,000 bacteria per cubic centimeter in crude sewage, 2,900,000 in a secondary-contact effluent, and 800,000 in the effluent from a trickling filter. The sewage contained 20,000, the contact effluent 4,000, and the trickling effluent 2,000 colon bacilli. At Plainfield, N. J., the double-contact filter was found to reduce the number of bacteria from an average of 1,000,000 per cubic centimeter to an average of 322,000; *B. coli* ranged from 1,000,000 to 100,000 in the sewage and from 100,000 to 10,000 in the effluent.[a] An experiment performed by Houston[b] is important in this connection: *B. pyocyaneus*, a pathogenic organism, was applied to the top of a trickling filter, and ten minutes later the bacillus appeared in the effluent, continuing to be discharged for ten days. In a similar manner the same organism was found to pass through a septic tank and a contact filter successively and to persist in both for nine days. At Baltimore, Md., the board of advisory engineers concluded that 95 per cent of the bacteria in the sewage could be removed by a system comprising a septic tank, 9-foot trickling filters, and supplementary sedimentation basins.[c] Such results are better than those usually obtained elsewhere, and if they can be maintained in practice they will go far toward solving the problem in that locality.

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[a] Johnson, Geo. A., Report on sewage purification at Columbus, Ohio, 1905.

[b] Thumm, K., and Pritzkow, A., Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, 1903, vol. 2, p. 127.

[c] Calmette, A., Recherches sur l'epuvation des eaux d'égout, Lille, 1907, vol. 2.

From a consideration of the available evidence it may be stated in a general way that coarse-grained, rapid sewage filters remove a considerable proportion of the sewage bacteria; that such removal has not been found to be sufficiently complete in practice to have great sanitary significance; that bacteria of various groups and certain specific organisms pass through such filters in practically the same proportions as the bacteria as a whole; and that, in the absence of any information to the contrary, it should be assumed that such filters have no greater effect on the typhoid and other pathogenic organisms than on *B. coli*, *B. pyocyaneus*, sewage streptococci, or the different groups of sewage bacteria.

THE NECESSITY FOR DISINFECTION.

It is probable that removal of bacteria will again be considered an essential factor in sewage purification. That it was so considered formerly is well known. The development of the modern rapid filter has made it possible to introduce sewage purification under conditions where it would have been impossible or prohibitively expensive in former days. In the acceptance of a partial solution of the problem much has been gained and but little lost. The process of purification that renders practically stable the offensive organic matter of sewage has accomplished the most important and in many cases the only essential requirement. If, however, sewage effluents find their way into the drinking waters of neighboring communities, the question of the relative responsibility of the settlements is debatable. It is generally conceded at present that efficient sewage purification should be undertaken by the communities in which the sewage originates, and hat purification of the water supply is the urgent duty of the other ommunities. As streams flowing through populous districts are necessarily contaminated and unfit for domestic use without filtration, t is considered unjust to require a community to purify its sewage to a higher degree bacterially than that shown by the stream into which it s discharged. On the other hand, in the fight against infectious diseases, sound tactics demand an attack on the enemy as near as possible to the initial source of infection. The best and easiest place to destroy typhoid germs is at the bedside of the typhoid patient; but this method can not be relied on to keep sewage free from infection, and the next strategic point is certainly the sewage. Once at large the germs may reach their victims in a score of well-known ways, and who will say by how many devious and unknown paths? With increasing knowledge of these facts and with improved processes and reduced cost of disinfection it is not too much to expect that the disinfection of sewage will some day be regarded as an integral part of its purification and as a necessary measure of protection for the community.

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[a] Rept. Sewerage Commission of New Jersey for 1906.

[b] Houston, A. C., Fourth Interim Rept. Royal Sewage Commission, 1904, vol. 3, p. 77.

[c] Report of the Board of Advisory Engineers to the Sewerage Commission of Baltimore, 1906.

One of the ways by which typhoid germs pass from the sewer to the victim is by means of shellfish fed or fattened in polluted water, and many of the oyster and clam beds of the eastern seaboard are subject to pollution by sewage. In England conditions are so serious that the demand for shellfish has perceptibly decreased. The situation presents obvious difficulties. The water of a polluted river may be rendered potable through filtration, but the purification of shellfish seems to be out of the question; it follows, therefore, that health must be safeguarded either by preventing the discharge of the bacteria of sewage on shellfish beds or by prohibiting the taking of the shellfish. In a large community where the shellfish industry is small it will probably be more satisfactory to adopt the latter method, but in small communities whose sewage pollutes large and important beds thorough bacterial purification is not an unreasonable requirement. Unfortunately the greatest shellfish areas of the country are situated near large cities, where they are subject directly or indirectly to possible pollution from sewage discharge.

In a carefully prepared paper on the pollution of shellfish beds, G. W. Fuller[a] states that the annual crop of oysters gathered along the Atlantic and Gulf coasts in 1902 amounted to more than 25,000,000 bushels, exceeding in value $13,000,000, and that the crop of clams was more than 2,000,000 bushels, valued at $2,000,000. Over one-half of this total production came from New Jersey, Maryland, and Virginia, and the shellfish were grown mainly in the waters of Delaware and Chesapeake bays, which receive the sewage from many large cities. At present this sewage is so enormously diluted by the bay waters that the danger of pollution is in most places remote, but it is present and ever increasing.

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[a] Concerning sewage disposal from the standpoint of the pollution of oysters and other shellfish, with especial reference to their transmission of typhoid fever: Jour. Franklin Inst., vol. 160, 1905, p. 82.

In Baltimore a system of sewerage and sewage disposal is being planned to remedy the already serious pollution of Patapsco River. In calling on a commission of experts for advice the sewerage commission of Baltimore specified "that the effluent proposed to be discharged into Chesapeake Bay or its tributaries in the system to be recommended by the engineers shall be of the highest practicable degree of purity." [a]

By agreement between the States of New Jersey and Pennsylvania the condition of Delaware River has been thoroughly investigated, and the pollution of that stream by sewage from Trenton, Bordentown, and other smaller communities in New Jersey, and Philadelphia, Easton, and other Pennsylvania cities, is prohibited after certain specified dates.[b] The necessity for protecting these valuable shellfish beds makes bacterial removal an essential feature in any scheme of sewage disposal which may be considered for such places.

The board of advisory engineers at Baltimore recommended that the settled trickling-filter effluent be given a final treatment on sand filters. The cost of works for the complete treatment of 75,000,000 gallons of sewage a day by septic tanks, trickling filters, sedimentation basins, and sand filters was estimated at $3,283,250, of which sum $1,040,750, or over 31 per cent, was for supplementary treatment. The annual cost of operation is expected to be $115,500, of which $55,000, or 48 per cent, is for supplementary treatment. This gives some idea of the cost of complete bacterial removal by filtration processes over and above the cost of reasonable organic purification. In regard to disinfection by chemical means the advisory engineers state: "To remove all bacteria remaining in the settled effluent from the sprinkling filters by disinfectants, such as hypochlorite of lime or of sodium or sulphate of copper, would be prohibitively expensive"—an authoritative opinion based on the best evidence then to be had. Almost no American data on chemical disinfection were available, and the results of experiments in Germany indicated that such disinfection could be accomplished only at high cost. The patented processes mainly used in England were also expensive. It was therefore desirable to learn just how effective disinfection processes could be made under conditions in America—how much they would cost, and what after effects, objectionable or otherwise, might follow their introduction.

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[a] Report of the Board of Advisory Engineers to the Sewerage Commission of Baltimore, 1906.

[b] Rept. New Jersey State Sewerage Commission, 1907.

review of the available data and a short experimental investiga- made in 1906 at Boston[a] led the writer to believe that there is h value in the process and that it might afford the best possible tion of the whole problem under certain conditions common in country, particularly in localities where the shellfish question is ›lved.

METHODS OF DISINFECTION.

CLASSIFICATION OF METHODS.

n Great Britain the somewhat indefinite allusions of the royal 'age commission to sterilization as a finishing process in sewage ıtment aroused a storm of discussion that resulted, at least, in ıring away many misconceptions. Sterilization processes of many .ds have been investigated, and the subject has been freely dis- ısed. For the following classification of sterilizing agents and for ıny of the facts noted here the writer is indebted to Rideal,[b] whose :efully prepared paper on the subject discusses its possibilities in a ɔroughly impartial manner. Other authorities are cited wherever ssible. Except when otherwise stated, costs are based on current ices in eastern markets.

The different methods and substances proposed for the sterilization effluents are considered in the following order:

.. Heat.
2. Lime.
3. Acids.
4. Ozone.
5. Chlorine and its compounds.
    (*a*) Chlorine gas.
    (*b*) Hypochlorites, or oxychlorides.
    (*c*) Electrolytic chlorine processes.
6. Copper and its compounds.
7. Miscellaneous.
    (*a*) Permanganates.
    (*b*) "Amines" process.
    (*c*) Sodium benzoate and other organic compounds.

HEAT.

The use of heat has been suggested for disinfecting sewage. In his estimony before the royal sewage commission E. E. Klein[c] referred o a patented process which he considered practicable, by the use of vhich sufficient ammonia could be recovered from the sewage nearly ›o pay for the treatment; but there is no record that this process has ever been used on a working scale. A device for heat interchange similar to that employed in the Forbes sterilizer may possibly, as is claimed, raise water to the boiling point and cool it again within 5° F. of the initial temperature. With coal at $3 per ton having a calorific value of 10,000 British thermal units, the fuel cost alone of such an operation would be about $7 per million gallons of sewage. The ammonia in a million gallons of Boston sewage, if in the form of sulphate, would have a market value of $20. Whether the difference between the value of the ammonium sulphate and the cost of the fuel is sufficient to cover the cost of operation, including labor, evaporation of the dilute solution, and all fixed charges can be determined only by actual experiment, but the plan is not wholly without possibilities.

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[a] Phelps, Earle B., and Carpenter, William T., The sterilization of sewage-filter effluents: Tech. Quart., ʋol. 19, 1906, p. 382; Contributions from the Sanitary Research Laboratory, vol. 4, 1908.

[b] Rideal, S., On the sterilization of effluents: Jour. Royal Sanitary Institute, vol. 26, p. 378.

[c] Interim Rept. Royal Sewage Commission, 1901, question 9674, p. 519.

LIME.

Caustic lime acts only slightly as a germicide, and the considerable removal of bacteria that takes place when lime is used as a precipitant in sewage is undoubtedly due to the action of the precipitate itself in dragging down with it the bacteria which it has entangled. Such action occurs to some extent in the precipitation of any substance, and even the sedimentation of sewage is always accompanied by reduction in the numbers of bacteria. Lime alone, therefore, would be of little value for sterilizing effluents. Rideal states that 60 to 70 grains per imperial gallon (860 to 1,000 parts per million) are inefficient in sterilization. Thresh, however, believes that lime would produce a satisfactory sterilization of effluents.[a]

ACIDS.

Most bacteria, and particularly typhoid and cholera germs, are more readily destroyed by acids than by alkalies. Rideal, therefore, considers it feasible to employ acids as germicides. He states that Stutzer found 0.05 per cent acid solutions fatal to bacteria in twenty-four hours; that Ivanoff found that 0.04 per cent to 0.08 per cent of acid destroyed the cholera germs in the sewage of Berlin and of Potsdam; that Kitasato found 0.08 per cent of sulphuric acid fatal to typhoid bacilli in fifteen minutes, and that he had himself obtained similar results. To furnish 1,000,000 gallons of sewage with 0.08 per cent of sulphuric acid requires 6,650 pounds of acid, costing approximately $73. Smaller amounts of acid might be used, as it would be unnecessary to kill typhoid germs in so short a time as fifteen minutes; but, on the other hand, most sewage contains a considerable amount of free alkali which must be neutralized before any germicidal effect of

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[a] Interim Rept. Royal Sewage Commission, 1901, question 8917, p. 502.

acid would be obtained. This process consequently would seem to
mpracticable except in emergencies. It is interesting to note that
sewage of Worcester, Mass., contains normally an average of 0.01
cent of free sulphuric acid, or half enough to kill cholera germs in
enty-four hours.

OZONE.

Ozone has been used more or less successfully in Germany, particu-
ly at Weisbaden, for sterilizing drinking water. Though the proc-
s has been most favorably commented on by those in immediate
arge of the investigations, it has not been generally regarded as
ccessful. The possibility of procuring a satisfactory effluent by
is process, when the water is that of a highly-polluted river is be-
ond question, but whether the process can satisfactorily treat a sew-
ge effluent of considerable turbidity has not been determined.
ideal calls attention to the fact that ozone is but sparingly soluble
water, and on that account it might fail to penetrate the solid
asses in the effluent, since the rate at which a dissolved gas will
enetrate solids in a liquid is a direct function of its solubility. The
rincipal cause of failure of the ozone process, however, seems to be
s expense. If this be true in waterworks it is hardly possible that
uch treatment could be applied to sewage effluents as an additional
afeguard after purification. Data are not at hand for estimating
he cost of applying ozone treatment to sewage effluents, but besides
he cost of operation there is the very considerable cost of installing
he necessary machinery and towers.

CHLORINE AND ITS COMPOUNDS.

GERMICIDAL ACTION.

Chlorine is well known as a powerful germicide. As a bleaching agent it acts on organic coloring matter indirectly by means of the free nascent oxygen which it liberates from the water in which it is dissolved, and it is probable that its germicidal action is similar. In other words, chlorine and ozone owe their germicidal power to the same thing—nascent oxygen. Chlorine, however, has the advantages of being cheap, of being more readily soluble, and of being obtainable in compounds that are easily transported and handled.

CHLORINE GAS.

Until within a few years chlorine has been manufactured commercially by the Weldon or some similar process. In the Weldon process hydrochloric acid is made to react with a complex mixture of manganese hydroxide and lime—"Weldon mud"—the re essentially

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2,$$

though in reality it is much more complex. Recentl electrolytic processes have been developed, by which manufacture has been materially reduced, particularly water power is available. Chlorine prepared by the mi mon salt, an acid, and a suitable oxidizing agent was used as early as 1800 by Cruikshank, who recommended dioxide and potassium bichromate as oxidizing agents. tions to the use of gaseous chlorine are chiefly the cost of tion, the difficulty and danger of handling the gas, and t of measuring accurately the amount of gas added to Furthermore, in disinfection free chlorine is not so effi hypochlorite.

Available chlorine, a term frequently used in the d chlorine disinfection methods, is determined by titratin with arsenious acid, or with some other reducing a represents in reality the oxidizing power of the substan in terms of chlorine. For example, hypochlorous acid ence of a reducing agent is decomposed according to t equation:

$$HClO = HCl + O.$$

The oxidizing power of this acid, or the available chlori fore, two hydrogen equivalents per molecule, which is tw chlorine content, a fact that makes the term availabl misnomer, but it has come into general use in the chlori and it is a convenient expression. In this article it signif power, determined against arsenious acid, and expressed chlorine.

HYPOCHLORITES.

Use in disinfection.—Chlorine is handled commercially of bleaching powder, or chloride of lime—an impure p posed largely of calcium hypochlorite. Bleaching powder containing from 35 per cent to 40 per cent of available be obtained in the market. The hypochlorite dissolv leaving a residue composed chiefly of calcium hydrate carbonate. Hypochlorites in general are made by add to caustic alkalies. Bleaching powder is made by passi rine gas over freshly-slaked lime. It is manufactured in in large amounts, the chlorine being obtained by the el salt. Abroad the chlorine is made by the older method oreign bleach is sold in this country in competition with the electroytic product. "Eau de Javelle" and "Labarraque's solution" are olutions of sodium hypochlorite. "Chloros," a commercial preparaion of sodium hypochlorite, contains 10 per cent by weight of available chlorine.

Hypochlorites have long been recognized as powerful and efficient isinfectants. The sodium and potassium compounds have not been enerally used on a large scale because of their relatively high cost nd the difficulty of preparing and keeping them in the dry state, but calcium hypochlorite has been extensively employed. The first Royal Sewage Commission of Great Britain used it in deodorizing London sewage in 1854.[a] The committee of 1885 of the American Public Health Association found it to be the best disinfectant available, cost and efficiency considered. It was used by Dibdin[b] in 1884 to deodorize the sewage of London, but it was not successful for that purpose and was later abandoned in favor of sodium permanganate. Its action on specific bacteria was studied by Nissen[c] in 1890. The use of bleaching powder as a sewage disinfectant has been more extensively studied in Germany than elsewhere. At the Hygienic Institute of Hamburg investigations have been made by Proskauer and Elsner, Dunbar and Zirn, Dunbar and Korn, Schumacher, and Schwarz. At the Royal Testing Station in Berlin, Kranepuhl and O. Kurpjuweit have each reported investigations.

Hamburg experiments.—Proskauer and Elsner[d] experimented at Hamburg with sewage which had been clarified by the Rothe-Degener system. They obtained satisfactory disinfection with chloride of lime, using concentrations of chlorine ranging from 2.7 to 4.0 parts per million, and ten minutes exposure sufficed practically to eliminate *B. coli.* Dunbar and Zirn[d] treated crude sewage and, in common with later workers, they imposed much more exacting standards of disinfection and used much greater concentrations of chlorine. After having employed cholera germs as test organisms, they concluded that the satisfactory disinfection of crude Hamburg sewage would require 25 parts per million of available chlorine and an exposure of two hours. Dunbar and Korn[e] studied the disinfection of crude sewage with special reference to its subsequent purification on biological filters. Schumacher[f] investigated the problem of disinfecting hospital sewages that had not received any previous treatment. In a preliminary set of bottle experiments he obtained the following results with the sewages of three hospitals.

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[a] Second Rept. Royal Sewage Commission, London, 1861.

[b] Dibdin, W. J., Jour. Assoc. Eng. Soc., vol. 40, 1908, p. 310.

[c] Zeit. Hyg., vol. 8, 1890, p. 62.

[d] Vierteljahrsschr. ger. Med., vol. 16, 1898, Suppl. Heft.

[e] Ges. Ing., vol. 27, 1904.

[f] Idem, 1905.

TABLE 3.—*Disinfection of three crude hospital sewages with chloride of lime.*

[Schumacher.]

Concentration of chloride of lime.	Hours of contact.	Bacteria per cubic centimeter. Initial content: 23,000,000. After treatment.	Initial content: 37,000,000. After treatment.	Initial content: 21,000,0 After treatment.
1 : 7,000	2	540	200	8,4
	4	140	260	[illegible]
	6	200	100	[illegible]
	24	160	20	[illegible]
1 : 5,000	2	60	60	10
	4	160	40	80
	6	120	....	60
	24	30	....	....
1 : 2,000	2	80	420	[illegible]
	4	20	....	[illegible]
	6	20	20	[illegible]
1 : 1,000	2	60	20	[illegible]
	4	120	40	[illegible]
	6	40	40	....

The amount of available chlorine in the chloride of lime used in these experiments is not stated, but it was probably not far from 30 per cent. On that assumption the concentration of available chlorine in the four sets of tests would be 43, 60, 150, and 300 parts per million, respectively. The high initial numbers indicate a very strong sewage. It is also worthy of note that the reduction in the number of bacteria with only 43 parts of chlorine is much greater than would be demanded in ordinary practice. Disinfection on a large scale was also conducted by the same investigator at two hospitals. After a storage period of two hours samples of one liter each were tested for *B. coli*. With a concentration of 1: 2,000, or about 150 parts per million of available chlorine, *B. coli* was isolated from a liter of water in only 6 samples out of 43, not being found in 88 per cent of the samples tested. With chloride of lime in the proportion of 1: 5,000, or about 60 parts per million of available chlorine, *B. coli* was destroyed in 62 per cent of the samples in two hours and in 64 per cent of the samples in four hours. Schwarz[a] called attention to the fact that excessive amounts of disinfectant are necessary on account of the large floating particles, a point previously commented on by Schumacher. Schwarz proposed, therefore, that all sewage should be carefully screened before disinfection in order to remove particles exceeding three millimeters in diameter. The screening of hospital sewage should be even more complete, removing particles exceeding one millimeter in diameter.

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[a] Ges. Ing., vol. 29, 1906, p. 773.

During experiments at the Eppendorfer purification works, a sewage low of about 60,000 United States gallons a day was available, and a tank holding about four hours' flow was used. As information was especially desired regarding the effect of the treatment on the cholera vibrio, an emulsion of another vibrio (Leuchtvibrionen) was added to the sewage at a regular rate before treatment, after it had been determined that this test organism would not only pass through the tank but would persist for days in the filters. Table 4 summarizes the results.

TABLE 4.—*Disinfection of the crude screened sewage of Eppendorfer, Germany, with chloride of lime.*

[Schwarz.]

Concentration of chloride of lime.[a]	Tests for vibrio in 1 cubic centimeter amounts.		Test for B. coli in 1 cubic centimeter amounts.		Final number of bacteria per cubic centimeter.[b]
	Total number of tests.	Number of positive tests.	Total number of tests.	Number of positive tests.	
1 : 2,000	....	....	17	0	15
1 : 5,000	51	0	51	1	23
1 : 10,000	28	0	7	0	36
1 : 20,000	15	0	6	0	72
1 : 30,000	10	0	....	....	3,620
1 : 40,000	8	4	....	....	59,000
Control	....	....	....	....	950,000

[a] 1 : 10,000 is about 30 parts per million of available chlorine, assuming that the chloride of lime contained 30 per cent of available chlorine.
[b] Initial number of bacteria per cubic centimeter, 1,350,000.

It was noted that a concentration of chloride of lime of 1: 2,000 materially affected the subsequent treatment of the disinfected sewage in trickling filters. Oxygen consumed and ammonia in the effluent were higher and nitrates lower than normal. An interesting fact noted was the production of chlorates in the filter, over 10 parts per million being recorded at one time. Schwarz concluded that sewage can be satisfactorily disinfected with chloride of lime after having been carefully passed through one millimeter mesh screens. One part in 5,000 (60 parts per million of available chlorine) was considered necessary for the destruction of typhoid germs and from one part in 7,000 to one part in 10,000 (30 to 40 parts of available chlorine) for cholera vibrio. The disinfected sewage can be subsequently purified without previous neutralization of the disinfectant.

Berlin experiments.—At the royal testing station in Berlin the subject of sewage disinfection has been studied by Kranepuhl[a] and by Kurpjuweit.[b] Kranepuhl undertook to determine the concentration of chloride of lime and the time of contact necessary to destroy the colon bacilli in crude Berlin sewage. These bacilli numbered about 100,000 per cubic centimeter. They were consi index of the pathogenicity of the sewage, because they numerous and more resistant than the pathogenic for bleaching powder employed contained available chlorin from 25 to 35 per cent. One liter samples of sewage wer with the desired amounts of chloride of lime, and at the of the specified time the remaining available chlorine w mined and was then neutralized with sterile sodium thi Nutrient broth was then added to the entire liter sample, a the sample was incubated. *B. coli* was sought in the sample by the usual means, and confirmatory tests for it w

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[a] Mitteilungen aus der Könighlichen Prufungsanstalt für Wasserversorgüng und Abwässerbeseitigung zu Berlin, vol. 9, 1907, p. 149.
[b] Idem, p. 162.

Kranepuhl's results are summarized in Table 5, in whic tests mean that *B. coli* was found in 1 liter.

TABLE 5.—*Disinfection of crude Berlin sewage with chloride of lin*

[Kranepuhl.]

Available chlorine (in parts per million.)	Time of exposure.	B. coli in liter samples.		
		Number of samples tested.	Number of positive tests.	Per cent of positive tests.
	Hours.			
50	2	20	11	55
50	4	9	2	22
60	2	17	6	35
60	4	6	3	50
150	2	19	4	21
150	4	10	1	10
300	2	16	1	6
300	4	7	0	0

Kurpjuweit[a] studied the penetration of solid particles b infectant. He made test cubes of gelatine having a volum 10 cubic centimeters, which he immersed in solutions of c lime for definite times, then removed and melted in wa after which he determined the available chlorine. He f amount of available chlorine to be a regular function of t exposure and of the concentration of the solution. The mos fact noted was the small quantity of chlorine actually For instance, a cube that had been immersed for ninety h a mean concentration of chlorine within its own volume but 1 per cent of the concentration of the solution. There shown to be a chemical combination between the chlorin gelatine. In order to determine whether such chlorine w in disinfection before it became combined, similar gelati inoculated with *B. coli* before setting, were immersed for in solutions containing from 60 to 3,000 parts per million of chlorine. The results in Table 6 were obtained.

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[a] Loc. cit.

TABLE 6.—*Destruction by chloride of lime of B. coli embedded in gelatine.*

[Kurpjuweit.]

Concentration of solution (average available chlorine in parts per million).	Number of B. coli remaining in 10 cubic centimeters after 2 hours.
ontrol)	91,500
	55,400
	43,500
	48,100
	6,600

The value of these results in practical work is problematic for several asons. The cubes employed are much larger than the particles that ould be in any sewage to be disinfected, and the character of the aterial is still more significant, because cubes of solid gelatine do ot represent in any way the porous, semisoluble masses that occur sewage. The question of penetration is an important one, and ere can be no doubt that the practical efficiency of disinfection rocesses is limited by the ability of the disinfectant to penetrate nall, solid particles that may be in the sewage. This point has een illustrated in a practical manner by Kurpjuweit's experiments. our samples of crude sewage were screened through sieves having penings 2, 5, 7, and 10 millimeters in diameter, respectively. Four ortions of each of the filtrates thus obtained were then treated with hloride of lime, so proportioned that the available chlorine was 150, 00, 600, and 3,000 parts per million, respectively. In the sewage hat was screened through a 2-millimeter mesh, 150 parts per million f available chlorine destroyed all the *B. coli* in four separate liter amples, while the same concentration of chlorine destroyed the *B. oli* in only 5 out of 8 liter samples screened through the 10-millimeter nesh. Indeed, 3,000 parts of available chlorine were required to emove completely the *B. coli* in the samples screened through the 0-millimeter mesh.

It should be noted that the investigators at Hamburg and at Berlin lealt wholly with crude sewage. Even when purification plants are n operation the disinfection is invariably applied first. No good eason for this procedure is obvious, unless it is that preliminary sedimentation tanks are available and supplementary tanks are not. In Germany the method of operation is possibly justified by the fact that the processes are being studied in order that they may be adopted for temporary use during epidemics, and it is not proposed to practice disinfection regularly. The expense of treating crude sewage, however, is at least twice that of treating a well-purified filter effluent. The very high standards that have been established for this work are also of interest. It is proposed so to treat a sewage containing ove 100,000 *B. coli* per cubic centimeter that the number of that kind bacillus will be reduced to less than one in a liter. The result ca hardly be expressed in per cent purification, and it is proper to inquir why such severe standards are employed. If the number of col bacilli were reduced even to one per cubic centimeter, it would mea a reduction of 99.999 per cent. It may safely be inferred that th number of typhoid and cholera germs would be reduced in about th same ratio, and furthermore that the number of typhoid and choler cases due to the discharge of this sewage would be similarly decrease In other words, if such disinfection were generally adopted, 99.99 cases of disease out of every 100,000, which are due, directly or indirectly, to sewage pollution, would be eliminated. Such reductio would seem to be very satisfactory, and yet it is proposed to improve this a thousand fold by insisting on an elimination of the colo bacilli from 1-liter samples, thus making the cost so great that i practically prohibits the use of the process, except for short periods during serious epidemics. It is well worth considering whether a continuous removal of 99 per cent of the disease germs is not a bette safeguard of the public health than an occasional complete remova during epidemics.

Experiments at Bengal, India.—The government of Bengal,[a] in 1904 appointed a commission to report on the pollution of Hooghly River by the effluents of septic tanks. Though the commission decided that the physical and chemical pollution of the river by the effluents was improbable, as sufficient dilution took place at all seasons to prevent any nuisance, bacterial purification of the effluents was deemed advisable. Experimental sand filters and copper sulphate disinfection satisfactorily removed the germs, but substitution of chloride of lime for the copper salt accomplished the same result at much less expense.

A septic tank installed near Calcutta was connected with a public latrine serving about 2,000 persons. From 400 gallons to 2,500 gallons of septic-tank effluent were daily treated with various amounts of chloride of lime, the available chlorine in which ranged from 20 to 60 parts per million. The numbers of bacteria initially present were not determined, but the final numbers are sufficiently low to indicate a satisfactory treatment. Furthermore, it was shown that increasing the concentration of the chlorine beyond a certain limit has very little effect on the residual bacteria. The results of this work are summarized in Table 7.

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[a] Indian government resolution on the working of septic tanks. Calcutta, January 6, 1906.

TABLE 7.—*Disinfection of septic sewage by chloride of lime at Bengal, India.*

Available chlorine (in parts per million).	Number of tests.	Number of samples.	Bacteria remaining (average number per cubic centimeter).
20	9	31	33
30	7	24	10
40	8	28	48
60	7	25	52

Experiments in Ohio.—In 1907 the Ohio State Board of Health studied the disinfection of sewage effluents in cooperation with the Bureau of Plant Industry of the United States Department of Agriculture. The results, reported by Kellerman, Pratt, and Kimberly,[a] related in part to the use of chloride of lime. The average results of four series of tests made with this disinfectant are summarized in Table 8.

TABLE 8.—*Disinfection of effluents with chloride of lime at Lancaster and at Marion, Ohio.*

[Kellerman, Pratt, and Kimberly.]

Series.	Available chlorine (in parts per million).	Number of bacteria per cubic centimeter at 20° C.		Number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter at 37° C.	
		Initial.	Final.	Initial.	Final.	Initial.	Final.
A	4.0	130,000	140	14,000	49	840	0
B	2.8	60,000	1,600	12,000	120	3,000	0
C	4.1	225,000	1,600	120,000	390	16,000	1
D	6.0	2,000,000	700,000	900,000	230,000	70,000	24,000

Each series represents a three-day test, during which 18 samples were examined in duplicate. Series A was made on the effluent of a sand filter at the Boys' Industrial School, Lancaster, and Series B, C, and D on the sand-filter effluent, contact-filter effluent, and septic-tank effluent, respectively, at Marion, Ohio. A subsequent study of the possibilities of treating the septic tank effluent at Marion led the authors to conclude that satisfactory disinfection could be accomplished by the use of sufficient bleaching powder to give 25 parts per million of available chlorine.

ELECTROLYTIC CHLORINE PROCESSES.

Electrolytic manufacture of chlorine.—When an electric current under a tension of not less than 2.5 volts is passed through a solution of common salt or of calcium or magnesium chloride, chlorine gas appears at one electrode and sodium hydroxide or the corresponding alk at the other. In the electrolytic manufacture of chlorine the pro ucts of the dissociation are kept apart and are removed from the c as quickly as possible, for if they are allowed to come together agai they immediately unite and form a hypochlorite. This method manufacturing hypochlorites has been employed in many of th so-called "electrolytic disinfection processes."

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[a] Kellerman, K. F., Pratt, R. W., and Kimberly, A. E., The disinfection of sewage effluents for the protection of public water supplies: Bull. 115, Bur. Plant Industry, U. S. Dept. Agr., 1907.

The Webster process.—One of the earliest electrolytic treatment was devised by Webster over twenty years ago, when, in 1889, h installed an experimental electrolytic plant at Crossness, England, t treat London sewage.[a] In his process crude sewage flowed betwee iron electrodes placed in long troughs, and an electric current wa passed from one electrode to the other at a tension of only two vol and a current density of 0.9 ampere per square foot of electrode. I was estimated that the treatment of 1,000,000 gallons of crude sew- age required the consumption of 240 pounds of iron and 450 kilowatt hours of electricity. Sedimentation followed the electrical treatment and a large amount of material was removed. In fact the proces was virtually one of chemical precipitation, the iron dissolved fro the electrode being first converted into hypochlorite, or other salt and then being decomposed by the alkali present and precipitated The solution of iron at the positive pole allowed the electrolyti reaction to proceed at a lower voltage than that required to liberate free chlorine. The results shown in Table 9 are the averages of 20 analyses, and they indicate the degree of purification obtained by the Webster process.

TABLE 9.—*Analyses of London sewage before and after treatment by the Webster process.*

	Parts per million.	
	Initial.	Final.
Suspended solids	333.5	15.6
Nitrogen as free ammonia	43.4	32.2
Albuminoid ammonia	5.0	2.0
Oxygen consumed	12.4	5.2

Though the process was originally conducted as a chemical precipitation, credit is due Webster for first pointing out the disinfecting value of the hypochlorites that are formed. T. M. Drown,[b] commenting on the process, observed that the American Public Health Association recognized the value of hypochlorites as early as 1888, and that their electrolytic manufacture was nothing new. Nevertheless its application to sewage was new and gave promise of success.

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[a] The Engineer, London, vol. 67, 1889, p. 261; also Eng. News, vol. 21, 1889, p. 338; vol. 22, 1889, p. 388.
[b] Jour. New England Waterworks Assoc., vol. 8, 1894, p. 135; also Eng. News, vol. 31, 1894, p. 236.

In a later paper before the British Medical Association[a] Webster lled attention to the possibilities of electrolyzing sea water and thus id the foundation for the many later processes that are based on that rinciple. A plant was later installed at Bradford, England, and in 890 Doctor McLintock stated that 70 per cent of the putrescible rganic matter of the sewage had been removed.[b]

Fermi,[c] after having investigated the process at the hygienic nstitute at Munich, concluded that the process is one of chemical recipitation and that it is more expensive than the lime process, nd similar conclusions were reached by König and Remele.[d]

The Woolf process—Electrozone.—Woolf's process differed from Webster's in that strong brine was electrolyzed, and the resultant hlorine and caustic soda were allowed to recombine to form sodium ypochlorite. The hypochlorite solution was then added to the sewage or water to be treated. In the spring of 1893 a plant of this kind was installed under the direction of the health department of New York City for treating the sewage of about 31 dwellings at Brewster, N. Y.,[e] a village situated on a small stream, the waters of which discharge into Croton Lake. The experiment was considered so successful that the health department installed a similar plant at the same place to discharge hypochlorite solution into Tonnetta Creek.[f] Sixteen hundred pounds of salt per million gallons of sewage were used, and the plant required an electric current of 700 amperes at 5 volts tension. This seems to have been the first plant established for the specific purpose of destroying bacteria; before that time the removal of organic matter had been the aim. An electrozone plant installed at Maidenhead, England, in 1897, was examined by Rideal, Robinson, and Kanthack in 1898. The bactericidal action was marked and the effluent was found to contain but few bacteria; this plant was not, however, continued[g] in operation. At Havana, Cuba, the Woolf process was employed for preparing a disinfectant solution to be used for treating the streets and the harbor.

The Hermite process.—The Hermite system differs from the Woolf system only in minor details. In reports on the process great stress is laid on the presence of magnesium hypochlorite in the electrolyzed solution, and there is much evidence that magnesium hypochlorite, owing probably to its lesser stability, is a more active agent than other hypochlorites. In later years this same fact has been observed, and it has been the basis of fanciful claims for patented processes, whose owners have invoked hypothetical oxides of chlorine to explain the results. A commission appointed by the London Lancet to investigate the Hermite process found that the solution obtained was similar to ordinary hypochlorite [a] in its chemical properties. A plant installed at Worthing, England, was investigated in 1894 by Kelly,[b] who reported that the hypochlorite solution contained from 0.22 to 0.75 gram per liter of available chlorine. The claim made for this solution—that mixed with equal parts of sewage it would instantly kill all germs—was not substantiated. A plant employing the Hermite process, established at Havre, France, in 1893, was investigated by a commission appointed by the imperial board of health of Germany and by one sent from Paris by the council of hygiene, and both bodies reported adversely. Other Hermite plants were installed at various places, but were finally abandoned. At Poplar, England, the Hermite solution is prepared on a large scale, and it is used for general disinfecting purposes as well as for street watering.

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[a] Eng. News, vol. 22, 1889, p. 388.

[b] Brit. Med. Jour., vol. 2, 1890, p. 498.

[c] Arch. f. Hyg., vol. 13, 1891, p. 207.

[d] Arch. f. Hyg., vol. 28, 1897, p. 185.

[e] Eng. News, vol. 30, 1893, p. 41.

[f] Eng. Record, vol. 29, 1894, p. 110; Elec. Eng., vol. 18, 1894, p. 101.

[g] Rideal, S., Sewage and its purification, 3d ed., New York, 1906, p. 185.

The oxychloride process.—The oxychloride process differs from the Hermite and Woolf processes only in matters of detail in the electrolytic cell. Greater efficiency than the older processes in the production of hypochlorites is claimed for it. At Guilford, England, Rideal made a test of the effect of oxychloride treatment on raw and septic sewages and on effluents of primary, secondary, and tertiary contact beds. The summary of his results given in Table 10 shows what was accomplished. The results, especially in respect to the removal of *B. coli*, are all that can be desired.

TABLE 10.—*Summary of Rideal's experiments on the use of oxychloride at Guilford, England.*

Source of sample.	Available chlorine parts per million.	Time of contact.	Number of organisms per cubic centimeter. Total. Initial.	Total. Final.	B. coli. Initial.	B. coli. Final less than—	B. enteritidis. Initial.	B. enteritidis. Final less than—
Sewage	30	4.3 hours	23,000,000	50,000	1,000,000	1.0	1,000	10.0
	50	do	23,000,000	20	1,000,000	.2	1,000	.2
	70	do	23,000,000	10	1,000,000	.2	1,000	.2
Septic effluent	25–44	1 to 4 hours	2,500,000–4,500,000	20–600	100,000–1,000,000	1.0–.2	10–1,000	1.0–.2
Effluent from first contact bed.	20	40 minutes	......	......	100,000	.2	......	......
	20	2 hours	......	......	......	......	20–100	.2
Effluent from second contact bed	10.6	......	1,000,000–2,000,000	40	1,000,000	.2	10–1,000	.2
Effluent from third contact bed.	2.5	1 hour	......	......	1,000–10,000	.2	......	......
	2.5	4.5 hours	......	......	......	......	10–100	1.0
	.5	0.5 hour	......	......	1,000–10,000	.2	......	......
	.5	4.5 hours	......	......	......	......	10–100	0.2

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[a] Lancet, vol. 1, 1894, p. 1321.

[b] Public Health, vol. 6, 1894, p. 261.

Examinations of the few organisms remaining in the sewages and ffluents after treatment showed them to be largely organisms of he hay bacillus group—aerobic spore-forming bacteria which are robably beneficial in the further oxidation of the organic matter. bsolute sterilization required very high concentration of chlorine.

COPPER AND ITS COMPOUNDS.

Moore and Kellerman, in 1904, suggested that copper sulphate be sed in water sterilization.[a] Since that time a great deal of experinental work has been done, mainly in connection with water. The nore important experiments, with sewage will be outlined.

Johnson and Copeland[b] at Columbus, Ohio, in 1904, in their work with trickling filter effluents, obtained the results given in Table 11.

TABLE 11.—*Disinfection of trickling filter effluents with copper sulphate at Columbus, Ohio.*

[Johnson and Copeland.]

	Copper sulphate in parts per million.	Reduction in bacteria (per cent).	
		In 3 hours.	In 24 hours.
First series, average of 3 sets	5	90.0	99.9
	10	98.0	99.95
	20	98.5	99.96
Second series, average of 3 sets	10	40.0	99.7
	20	60.0	99.9
	40	88.0	99.95

They found the action of copper sulphate to be most rapid during the first hour. They estimate the cost for chemicals alone at $5 per million gallons of effluent treated with 10 parts per million of copper sulphate, and $10 if treated with 20 parts per million—an expense which they consider prohibitive.

The use of copper sulphate as a disinfectant was more thoroughly investigated by Johnson at Columbus in 1905.[c] Experiments were made with crude sewage, and with effluents from trickling, contact, and sand filters. The effect of temperature, of organic matter, and of alkalinity on the efficiency of the process were determined and special studies were also made to determine the effect of the treatment on colon and typhoid organisms. The principal results with the various sewages treated are summarized in Table 12.

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[a] U. S. Dept. Agr., Bureau of Plant Industry, Bull. 64, 1904.

[b] Jour. Infect. Diseases, Suppl. No. 1, 1905, p. 327; also Reports and papers, Am. Pub. Health Assoc. vol. 30, pt. 2, p. 327.

[c] Report on sewage purification at Columbus, Ohio, 1905, p. 471; also Jour. New England Waterworks Assoc., 1905, p. 474.

TABLE 12.—*Results of disinfection of sewage and effluents with copper sulphate at Columbus, Ohio; total number of bacteria remaining after contact periods of one hour and of three hours.*[a]

[Johnson.]

Copper sulphate (in parts per million.)	Series A.	Series B.		Series C.		Series D.	
	1 hour.	1 hour.	3 hours.	1 hour.	3 hours.	1 hour.	3 hours.
1,000	3,000	1,000	240	430	60	2,100	280
200	....	5,000	600	1,100	130	6,000	1,400
100	9,000	6,000	500	2,100	230	5,500	1,800
40	....	3,400	700	1,200	230	6,500	1,300
20	14,000	11,000	1,900	3,500	600	13,000	2,600
10	....	21,000	4,500	7,500	1,200	20,000	5,000

	Bacteria per cc.
[a] Series A. Crude sewage; initial number	1,200,000
B. Effluent of sprinkling filter	1,000,000
C. Effluent of contact filter	400,000
D. Effluent of sand filter	280,000

Each series is the average of from three to five sets of tests.

Longer periods of contact up to twenty-four hours gave results of no additional significance, except that when the lower concentrations of copper were used the number of bacteria showed a decided increase after about the third hour, an indication that the copper was removed from solution, probably by combination either with the organic matter or with carbonic acid. Subsequent increase in number of bacteria is a phenomenon of frequent occurrence in disinfection work. It is in fact neither possible nor desirable to prevent perpetually the feeding of bacteria on the organic matter of the disinfected effluents. The significant fact in Johnson's tests is that the bacteria originally present were practically eliminated, and it may safely be assumed that under conditions existing in a stream there would be no multiplication of the typhoid or other pathogenic bacteria.

Two important facts were brought out in this study. The disinfection obtained with 100 parts per million of copper sulphate is, for practical purposes, but little better than that obtained with 10 parts, and results obtained in a one-hour contact are practically as good as those obtained in a three-hour contact. Johnson's work was done at summer temperature, and in order to determine the effect of temperature on the germicidal action parallel experiments were conducted at 5° and at 20° C. It was found in general that a result which could be obtained at the higher temperature in thirty minutes would be attained at the lower temperature in about three hours. This is a point that has usually been overlooked, and it is of special significance in practical operation, as effluents in the northern latitudes would have a temperature of about 5° C. during much of the year. It is interesting to note that temperature has little effect on the germicidal efficiency of hypochlorites.

The combined effect of organic matter and alkalinity was determined by treating the undiluted effluent and the same effluent after being diluted 1 to 1 and 1 to 2 with tap water. The effect was decidedly noticeable in the weaker concentrations of copper sulphate, and much less so where the concentrations of copper were excessive. The results with 10 parts of copper sulphate per million are summarized in Table 13.

TABLE 13.—*Effect of organic matter and of alkalinity on the germicidal properties of copper sulphate: per cent removal of bacteria at end of one hour's contact with 10 parts per million of copper sulphate.*

[Johnson.]

Source of sample.	Dilution.		
	0	1:1	1:2
Crude sewage	96.1	97.5	98.5
Trickling filter effluent	97.3	99.0	99.1
Sand filter effluent	70	86	91

The efficiency of copper sulphate as a disinfectant was investigated in 1906 at the Sanitary Research Laboratory of the Massachusetts Institute of Technology by treating the effluent from an 8-foot trickling filter. Table 14 gives the average results divided into two periods to show the effect of temperature of the effluent. At the conclusion of the tests a composite sample of the sediment drawn from the sedimentation tank during the experiment was analyzed. The copper contained in the sediment accounted very closely for the total amount of copper added, a fact that makes it apparent that little copper left the tank in soluble form.

TABLE 14.—*Disinfection of trickling filter effluent with copper sulphate at Boston, Mass.; average results.*

Period.	Copper sulphate (in parts per million).	Temperature.	Number of bacteria per cubic centimeter.			Number of B. coli [a] per cubic centimeter.		
			Initial.	Final.	Per cent removed.	Initial.	Final.	Per cent removed.
1906.		°*F.*						
October 13-31	4	56	230,000	14,000	94.0	44,000	640	98.5
November 3-19	4	46	250,000	51,000	80.0	48,000	770	98.4
November 21-December 10	8	43	240,000	5,000	97.9	32,000	390	98.8

[a] Jackson's bile media used.

The work of Kellerman, Pratt, and Kimberly in Ohio during the winter of 1906-7 consisted mainly of experiments with copper sulphate as a disinfectant. Their investigations, probably the most comprehensive ever made with copper sulphate, were conducted under actual working conditions and with several kinds of effluent. The chemical composition of the water, particularly in regard to its hardening constituents, was found to exert an important influence on the results. Their original paper[a] on the subject contains complete chemical analyses of the effluents treated. Table 15, containing a brief summary of average results calculated from the original tables, shows in a general way what was accomplished. The authors concluded that copper sulphate is not so efficient as chlorine compounds, is more seriously affected by carbonates, and is much more expensive.

TABLE 15.—*Disinfection of effluents with copper sulphate in Ohio.*

[Kellerman, Pratt, and Kimberly.]

Series.	Copper sulphate (in parts per million.)	Number of bacteria per cubic centimeter at 20° C.		Number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter.	
		Initial.	Final.	Initial.	Final.	Initial.	Final.
A	5	6,000,000	1,200,000	140,000	120,000	6,000	600
	6.7	250,000	70,000	19,000	10,000	6,000	900
	10	60,000	16,000	47,000	10,000	2,600	1,000
	13	65,000	23,000	37,000	5,500	4,600	600
	20	120,000	20,000	8,000	11,000	1,600	110
	29	60,000	3,900	24,000	6,000	1,200	10
	40	160,000	8,500	75,000	4,700	5,500	110
	67	200,000	34,000	81,000	14,000	7,000	700
B	7.3	110,000	23,000	12,000	1,800	600	45
	14	75,000	9,500	16,000	600	75	0
	22	55,000	7,000	5,500	200	75	0
C	6.5	390,000	110,000	170,000	41,000	8,000	3,000
	15	230,000	65,000	42,000	16,000	5,000	2,200
	40	29,000	6,000	30,000	8,500	5,500	750
	116	84,000	7,000	28,000	2,000	5,000	560

A. Effluent of contact filter at Westerville, Ohio.
B. Effluent of sand filter at Lancaster, Ohio.
C. Effluent of sand filter at Marion, Ohio.

MISCELLANEOUS METHODS.

PERMANGANATES.

Potassium permanganate and sodium permanganate have been used for the oxidation of organic matter in streams. At London when the Thames becomes extremely foul during low-water periods, sodium permanganate is added to its waters in order to destroy odors and putrescible material, but the treatment undoubtedly results in partly sterilizing the water. It is claimed that the germicidal action is not sufficiently great to interfere with the normal oxidizing changes in the stream. The use of permanganates has been proposed for rendering effluents of chemical precipitation plants nonputrescible.

"AMINES" PROCESS.

The so-called "amines" process was developed by H. Wollheim in England. It is claimed that trimethylamine treated with lime or other alkali produces a very poisonous substance. Herring brine is used to supply the amine. A large excess of lime is added and the mixture is used to precipitate crude sewage. Klein made a test of he process at West Horn in 1889, and found that a clear, nonpurescent, sterile effluent could be obtained. Similar results were obtained at Wimbledon,[a] where 768,000 bacteria per cubic centimeter in the sewage were completely removed. The sludge is also nonputrescible. The process does not seem to have been further developed.

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[a] Kellerman, K. T., Pratt, R. W., and Kimberly, A. E.: The disinfection of sewage effluents for the protection of public water supplies, Bull. 115, Bur. Plant Industry, U. S. Dept. Agr. 1907.

SODIUM BENZOATE AND OTHER ORGANIC COMPOUNDS.

Sodium benzoate is supposed to possess powerful germicidal properties, and its use as a disinfectant for sewage was suggested to the writer. It would apparently have the distinct advantage over such other disinfectants as chlorine and copper salts of not combining with organic matter, thus rendering all the disinfectant added available for a long time. Sodium benzoate was applied regularly to a trickling filter effluent at Boston during March and April, 1907. An addition of commercial benzoate at the rate of 0.8 part per million for twenty-six days gave an average reduction of total bacteria from 140,000 to 54,000 per cubic centimeter, or a 62 per cent removal. Doubling the amount of benzoate increased the efficiency somewhat, the average reduction then being from 370,000 to 84,000 per cubic centimeter, or 78 per cent. The cost of benzoate for the treatment is $1 per million gallons for 0.8 part and $2 for twice that quantity. Obviously this substance is not an efficient disinfectant in sewage work.

Other organic substances, such as the phenols and the coal-tar products, were suggested, but in general their high cost eliminates them from consideration. The possibility of after effects must also be considered. There is a certain advantage in the use of a substance which is itself used up in the reaction or which is converted into harmless compounds. On the other hand, the organic disinfectants are extremely powerful and there is always a chance of the discovery of some new compound with the requisite germicidal properties and the low cost that will make it the ideal sewage disinfectant.

SUMMARY OF DISINFECTION METHODS.

Two of the methods of disinfection that have been mentioned appear not to have been sufficiently investigated, namely, disinfection by heat and by organic compounds. The heat method holds a reasonable possibility that sufficient ammonia may be recovered to pay for the necessary heating, but actual trial is essential for convincing proof. A systematic study of organic compounds as disinfectants has yet to be made.

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[a] Interim Rept. Royal Sewage Commission, 1901, p. 304.

Of the disinfectants that have been sufficiently investigated, chlorine compounds and copper salts alone appear to be applicable to the sewage problem. Moreover, a detailed study of results on a cost basis leaves no doubt that the efficiency of chlorine is much greater than that of copper. Even if the prices of these two materials were more nearly equal, many facts favor the use of chlorine. Both reagents unite with organic matter, but chlorine unites by oxidizing the organic matter, thus rendering it less putrescible, while copper precipitates it. The compounds formed by the copper tend to protect the solid particles from further action, and the diffusion of copper ions through such a precipitated copper envelope must necessarily be slow. As no such action occurs with chlorine compounds, the penetration of the chlorine into solid particles must be much more complete. Chlorine in the form of bleaching powder is to some extent a by-product, is very cheap, and will probably become cheaper as the methods of production are improved; on the other hand, copper is a staple, the price of which is likely to increase. Sewages may be found of such chemical composition that treatment with copper will be more effective than that with chlorine, but in general chlorine compounds are to-day by far the most economical and the most efficient disinfectants available in sewage work.

EXPERIMENTAL INVESTIGATIONS.

HISTORY.

In connection with general investigations in sewage disposal, which have been conducted since 1903 at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology, the subject of the chemical disinfection of sewage and sewage effluents has been extensively studied during the past two years. In the spring of 1906 a cooperative arrangement between the United States Geological Survey and the institute made it possible materially to enlarge the scope of the work.

With a view also of gaining increased knowledge of the practical workings of the processes that had been developed at Boston, an arrangement was made with the state sewerage commission of New Jersey, through Boyd McLean, secretary, under which experiments were begun at Red Bank, N. J. The state sewerage commission later continued that work for its own information, retaining the writer in charge, and through the courtesy of the commission the results of the entire work are here presented. During the summer of 1907 the experiments were placed under the immediate charge of F. E. Daniels, to whose faithful efforts their successful completion is in large part due. Mr. Daniels was assisted at Red Bank by H. S. Crawford, and also did much of the work at Boston during 1908.

In December, 1907, the scope of the investigation was still further broadened by a cooperative agreement between the United States Geological Survey and the sewerage commission of Baltimore, of which Brig. Gen. Peter Leary, U. S. Army, retired, is chairman, and Calvin W. Hendrick is chief engineer. Experiments on a somewhat enlarged scale were immediately undertaken at the Walbrook testing station of the Baltimore sewerage commission, and they were continued up to July, 1908, at which date the agreement with the Geological Survey lapsed. The work at Baltimore was under the immediate charge of Ezra B. Whitman, division engineer of the disposal division, to whom the writer is under the greatest obligation for its successful outcome. Intimately associated with that work also and responsible in large measure for the results have been Charles A. Emerson, jr., assistant division engineer, Henry C. McRae, chemist, and Edward G. Birge, bacteriologist. Dr. R. P. Cowles, of Johns Hopkins University, and William T. Carpenter, Leyland Whipple, and Marvin H. Lillis, have also been associated with this work from time to time in connection with special lines of investigation.

Through the courtesy of A. G. Paine, jr., president, and J. R. Crocker, superintendent, of the McDonald Electrolytic Cell Company, of New York, an electrolytic chlorine cell having a capacity of 22 pounds a day of chlorine gas was placed at the disposal of the writer, and it proved to be of great assistance in the work, as a large supply of gaseous chlorine was thus made available for special experiments. The machine was used directly in disinfection and also in the preparation of a series of chlorine compounds that were studied.

BACTERIOLOGICAL METHODS AND EXPRESSION OF RESULTS.

The bacteriological methods employed in the different parts of this work have been kept as nearly uniform as possible in order that the results may be strictly comparable. In general, the methods have been those recommended by the committee on standard methods of water analysis of the American Public Health Association, laboratory section. Since the publication of those methods,[a] a new presumptive test for the colon bacillus has been described by Jackson [b] and it has been used throughout this work. The medium employed in this test consists of ox bile to which lactose has been added. Its accuracy in sewage work has never been carefully studied, but recent studies by Prescott and Winslow [c] have confirmed the earlier statement of Jackson that in water work this presumptive test gives results which are similar to those obtained in complete *B. coli* determinations. It may fairly be assumed, therefore, that the *B. coli* results reported in the present paper represent a group of bacteria, including practically all the *B. coli* actually present, together with certain other bacteria which probably are not more than 10 per cent of the whole number reported. The study of such a group gives valuable information concerning the probable elimination of typhoid and other pathogenic bacteria, while the additional information to be obtained from a complete determination of the *B. coli* actually present is not deemed sufficient to warrant the additional labor involved. At Boston and at Baltimore counts of the bacteria on gelatin at 20° C. and on litmus lactose agar at 37° C. and counts of the acid-forming bacteria at 37° C. were recorded. The latter group includes the *B. coli*, and some bacteriologists believe that the number of acid-forming bacteria is a more accurate indication of the numbers of colon bacilli than the presumptive tests. It is indisputable, however, that the group of acid-forming bacteria is large and that in sewage work at least it bears only a general relationship to *B. coli*. An additional group, the bacteria that liquefy gelatin, is also included in the Boston results, though the additional information afforded by including this group is slight. Inasmuch as adequate facilities for complete bacteriological work were not available at Red Bank, the total count at 20° C. and the presumptive *B. coli* tests alone were made. Examinations of the trickling filter effluent before and after treatment have been made at Boston on five or six days in each week. At Red Bank and at Baltimore two samples were tested each working day for *B. coli* and three samples were plated for the bacterial counts.

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[a] Jour. Infect. Dis. Suppl. 1, Chicago, 1905. Repts. and Papers American Pub. Health Assoc., vol. 30, pt. 2, 1905.

[b] Biological studies by the pupils of William Thompson Sedgwick, p. 292, Boston, 1906.

[c] Elements of water bacteriology, 2d ed., New York, 1908, p. 149.

Considerable thought has been given to the manner of expressing results. It would obviously be inadvisable to attempt to tabulate the results of all examinations made, because such tables would be too unwieldy for general use. On the other hand, the use of averages, especially if they cover long periods, is open to the serious objection that a few bad results are easily covered up in general averages, and it is particularly necessary, in a process of this kind, to show that the results are not only satisfactory in general, but that they are fairly uniform. To cite a familiar illustration, a poor marksman's shots might be placed symmetrically about the center of the target and in that sense their average position might be as near the bull's-eye as the average position of better-placed shots. The actual deviations from the average position would indicate the character of the shooting. Similarly, in disinfection two series of tests might give the same average, even if one series were composed of fairly uniform results and the other series of very erratic ones. In other words, the deviations from the average are fully as significant as the average figure itself. Accordingly, the routine work is reported in the form of weekly averages. The total bacterial counts are accompanied by a statement showing the variations of the individual results and the variations of the individual bacterial removals from the average bacterial removal. In this way the record of what was actually accomplished is stated in the most compact form.

A new method of recording *B. coli* results is also employed. The procedures used in the determination of this organism do not permit a quantitative count of the number really present, but show merely the presence or the absence of the bacillus. Quantitative results are obtained in a rough way by applying the test to various dilutions of the sample. For instance, in a disinfected effluent the test is applied on 0.1, 0.01, and 0.001 cubic centimeter, respectively, and the highest dilution giving a positive test is recorded. Hitherto a bare statement of the results is all that has been attempted in the way of giving quantitative significance to this test. But it has been shown[a] that where as many as fifty or one hundred results of that character from the same source are available, the probability law of distribution may be applied in order to estimate the average number of organisms present. The most probable value for the number of *B. coli* present in each sample is indicated by the reciprocal of the highest dilution giving a positive test, and while that figure may be far from the correct one for any one sample, the average of fifty estimates of this character closely approximates the actual value. The case is analogous to the well-known facts in relation to the expectancy of life at any age; an expectancy of life as given in the actuarial tables has but little weight when applied to any one person, but in the average of a large number of persons it approximates the truth. The number of *B. coli* present in a sample has therefore been recorded in this way. Individual results have but little weight and weekly averages must be properly interpreted, but monthly averages are probably very near the average numbers.

INVESTIGATIONS AT BOSTON.

SCOPE AND CHARACTER OF EXPERIMENTS.

Since the beginning of the work at Boston in February, 1906, various phases of the disinfection problem have been under investigation. The following summary of the studies shows their scope and character: (*a*) Preliminary experiments with chloride of lime; (*b*) studies of the comparative efficiencies of chloride of lime, sulphate of copper, and sodium benzoate; (*c*) small-scale experiments to determine the comparative efficiencies of free chlorine, commercial hypochlorites, electrolytic hypochlorites, chlorates and perchlorates, and the hypochlorites of several bases; (*d*) studies of the comparative effect of hypochlorites on the typhoid and the colon bacilli; (*e*) routine disinfection of 5,000 gallons a day of trickling-filter effluent with chloride of lime; (*f*) disinfection of crude sewage with chloride of lime in 700-gallon tests. The studies on copper sulphate and sodium benzoate have already been discussed (pp. 29–32). The remaining divisions of the work are reviewed in the succeeding pages.

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[a] Phelps, E. B., A method for calculating the numbers of *B. coli* from the results of dilution tests: Am. Jour. Pub. Hyg., vol. 18, 1908, p. 141.

PRELIMINARY EXPERIMENTS WITH CHLORIDE OF LIME.

The results of some preliminary experiments in the spring of 1906 have already been published,[a] but as they have important bearing on the present work, a brief review of them is here presented. The experiments were made with chloride of lime and the effluent of a trickling filter in which Boston sewage was being treated. They consisted of 23 bottle tests in which the available chlorine that was added varied from 0.25 to 100 parts per million, and the time of contact from thirty minutes to twenty-four hours. They were undertaken with the object of establishing practical working limits for available chlorine and contact period for future experiments, and particularly to determine whether the English and Continental practice of adding large, almost prohibitive, amounts of chlorine is justified by the results.

This preliminary study indicated that an effluent similar to the one used can be deprived of 95 per cent to 98 per cent of its total bacteria in two hours by the application of chloride of lime in concentrations having 2 to 5 parts per million of available chlorine. The impracticability of attempting to get much better results was well shown, for complete sterilization was never accomplished, though concentrations of chlorine up to 100 parts per million and storage periods of twenty-four hours were employed. It was found unnecessary, in brief, to use more than 5 parts of chlorine or to treat for over two hours.

It is a well-known fact that, in all processes involving the destruction of bacteria, it is comparatively easy to kill the first 95 per cent of the germs and very difficult to destroy the remaining 5 per cent. This phenomenon of the "resistant minority," as Whipple terms it, is common to all kinds of sterilization, whether it be by heat, cold, light, chemicals, or other means. It is therefore more practical to determine how far disinfection may be carried at a reasonable expenditure than to attempt the ideal complete sterilization. To state a concrete example, it might happen that the pathogenicity of an effluent could be reduced 96 per cent by the expenditure of a certain sum of money, 97 per cent by the expenditure of twice that sum, and 99 per cent by the expenditure of five times that sum. The first reduction might represent a feasible plan, and the last a proitively expensive one. It is plainly more desirable at the outset determine the relations between the various factors, such as con- tration of disinfectant, time of contact, cost, and efficiency, and establish certain working limits with reference to final costs, an to attempt the ultimate destruction of all germs regardless of e practical limits that necessarily exist. The preliminary experi- ents were undertaken with the idea of fixing these practical work- g limits. For the first time in the history of the subject the disin- ction of sewage filter effluents and even of crude sewage itself was own to be practicable and feasible, yielding results commensurate ith the cost when compared with the results and costs of other urification processes.

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[a] Phelps, E. B., and Carpenter, Wm. T., The sterilization of sewage filter effluents: Tech. Quart., vol. 19, 1906, pp. 382–403.

DISINFECTION OF TRICKLING-FILTER EFFLUENT.

The most important work at Boston consisted in the routine isinfection of the combined effluents of two trickling filters. Each ilter is 8 feet deep and has a surface area of 50 square feet. One is omposed of crushed stone from 1 inch to 1½ inches in mean diam- eter; the other of stone from 1½ to 2 inches in diameter. The com- ined effluents, amounting to 5,000 gallons in twenty-four hours, were brought from the underdrains of the outdoor trickling filters to the filter house through a short length of iron pipe. Within the filter house the liquid was conducted by an open trough to the central channel of a sedimentation tank built on the Dortmund plan. It then passed downward nearly to the bottom of this conical tank, entered the main body of the tank, and, rising with constantly decreasing velocity, finally overflowed at the surface. The tank was designed to give a two-hour storage period. The disinfectant solution was made up in a 50-gallon barrel to a strength about one hundred times that required in the final mixture. A small orifice-box working under constant head was connected with the barrel and was designed to deliver exactly 2 gallons an hour. As the flow through the sedimentation tank was a little over 200 gallons per hour, this arrangement gave a final mixture of the desired proportions. These rates and volumes were kept constant throughout, any change in the amount of disinfectant added being brought about by changing the strength of the solution. Readings of a float gauge set in the barrel and daily measurements of the flow of the trickling-filter effluent into the tank served as checks on the accuracy of the dilutions, and together with daily analyses of the strong disinfecting solution, gave data from which the actual amount of disinfectant added during any required period of time could be computed. Observations of the rate of flow of the disinfectant solution into the tank were made at hourly intervals for a period of three hours preceding the taking of samples, and the actual concentration of the disinfectant corresponding to the sample in question was calculated from these observations. The disinfectant solution flowed into the open trough previously mentioned, where it mingled with the effluent. Further opportunity for mixing occurred during the passage down the central channel of the sedimentation tank. Samples for bacterial examination were collected with the usual precautions, before the effluent had reached the wooden trough into which the disinfectant solution was run and also at the final outlet of the sedimentation tank after the combined effluent and disinfectant had been in contact for a period somewhat less than two hours. These samples are described as initial and final, respectively.

The chemical composition of an effluent has an important influence on the germicidal value of most disinfectants, particularly chloride of lime. The chlorine applied is eventually completely consumed by chemical reaction with the organic matter of the effluent, and the germicidal action takes place in the interval of time between the addition of the chlorine and its final exhaustion by chemical reaction. The amount of organic matter present, therefore, practically determines the amount of chlorine that it is necessary to use. For this reason the chemical analyses of the combined effluent are recorded by monthly averages in Table 16. The monthly averages of the analyses of the disinfected and settled effluent are also included to show the chemical character of the effluent after treatment.

TABLE 16.—*Chemical analyses of trickling-filter effluent at Boston before and after disinfection with chloride of lime and sedimentation; monthly averages.*

[Parts per million.]

INITIAL.

Month.	Turbidity.	Suspended solids.		Nitrogen as—					Oxygen consumed.[a]		Dissolved oxygen.
		Total.	Loss on ignition.	Organic.		Free ammonia.	Nitrites.	Nitrates.	Total.	Dissolved.	
				Total.	Dissolved.						
1907.											
November	135	118	78	3.5	1.5	15.0	0.2	2.0	40	32	8.2
December	155	......	......	5.5	3.0	15.5	0.1	1.0	38	33	7.8
1908.											
January	140	92	69	5.0	3.0	15.0	0.3	3.5	45	38	10.0
February	145	177	156	6.0	2.5	14.5	0.1	3.0	44	32	12.5
March	130	180	122	7.5	3.5	15.5	0.2	4.0	48	35	7.8
April	195	313	192	10.5	5.5	14.5	0.4	5.5	64	46	9.4
May	275	436	247	14.0	4.5	14.5	0.9	6.0	70	35	7.4
June	155	174	96	11.5	6.0	7.5	0.8	6.0	49	35	7.1
Average	165	213	137	8.0	4.0	14.0	0.4	4.0	50	36	8.8

FINAL.

1907.											
November	105	71	53	3.0	1.5	14.5	0.1	2.0	28	27	....
December	145	......	......	4.0	1.5	14.0	0.1	2.0	39	38	....
1908.											
January	115	124	103	3.0	3.0	13.0	0.6	5.0	49	41	....
February	110	259	239	4.5	2.5	13.5	0.3	4.5	42	38	....
March	125	125	82	9.5	3.5	15.0	0.3	3.5	46	42	....
April	105	147	125	5.5	3.5	14.5	0.4	5.0	44	40	....
May	135	92	69	5.0	3.0	15.0	1.0	5.0	44	33	....
June	95	51	43	7.0	4.0	7.5	0.8	6.0	38	33	....
Average	115	124	102	5.0	3.0	13.5	0.5	4.0	41	37	....

[a] Thirty-minute boiling method.

This disinfection experiment was started November 11, 1907, and was continued practically without interruption till June 27, 1908, a period of thirty-three weeks. The value of such continuous experiment is obvious. A certain length of time is always required for for the establishment of uniform working conditions, not only in the personal element but in the tanks themselves. Furthermore, short special experiments receive an unusual and perhaps unfair amount of care and attention, which is not bestowed on work that has become part of the routine, and the natural defects of the processes under practical working conditions are, therefore, not always discovered. The most important value of long-continued tests, however, lies in their being carried out under various seasonal conditions. Fluctuating conditions of temperature and rainfall fundamentally affect the sewage and influence the work of the filter. It is consequently of prime importance to determine the efficiency of any purification process under an extreme range of seasonal conditions. It fortunately happened that the present experiments were continued through an unusually cold winter and through the hottest portions of an exceptionally hot, dry summer.

Table 17 contains the results of the experiments, given in weekly averages, which are the mean of four to six daily results. During the first five weeks the available chlorine added was about six parts per million, but during the remainder of the period this concentration was reduced to between two and four parts without materially affecting the results. The average results for the whole period are indicated in the last line of the table.

TABLE 17.—*Disinfection of trickling-filter effluent with chloride of lime at Boston; weekly averages.*

Week ending—	Temperature.	Available Cl (parts per million).	Number of bacteria per cubic centimeter at 20° C.				Number of bacteria per cubic centimeter at 37° C.				Number of B. coli per cubic centimeter.[a]	
			Total.		Liquefiers.		Total.		Acid formers.			
			Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.
1907.												
November 16	45	5.7	1,100,000	1,800	150,000	100	330,000	570	250,000	22	260,000	4
23	46	5.9	800,000	7,500	46,000	600	130,000	500	94,000	250	180,000	20
30	42	6.8	1,000,000	1,800	48,000	43	65,000	600	48,000	110	26,000	1
December 7	36	6.9	600,000	4,500	60,000	90	140,000	140	85,000	44	17,000	0
14	42	5.0	800,000	15,000	60,000	750	140,000	1,500	43,000	850	5,500	33
21	37	3.0	550,000	85,000	27,000	4,500	95,000	6,500	75,000	5,500	4,000	370
28	44	3.1	850,000	20,000	120,000	2,400	210,000	3,400	66,000	1,900	46,000	600
1908.												
January 4	40	2.8	950,000	7,000	70,000	500	90,000	500	70,000	370	65,000	25
11	35	3.2	550,000	17,000	55,000	450	86,000	2,100	50,000	1,900	55,000	750
18	34	2.7	550,000	22,000	47,000	1,300	80,000	1,300	80,000	1,200	8,500	520
25	35	2.7	800,000	35,000	26,000	2,800	110,000	6,000	100,000	5,500	64,000	60
February 1	34	3.3	450,000	75,000	30,000	4,000	70,000	16,000	55,000	11,000	2,500	230
8	33	3.6	800,000	8,000	60,000	400	340,000	2,000	200,000	1,100	10,000	100
15	35	3.4	650,000	43,000	30,000	250	60,000	2,500	50,000	2,000	33,000	280
22	34	3.4	390,000	17,000	24,000	900	74,000	2,600	52,000	2,000	10,000	400
29	34	3.3	550,000	13,000	40,000	100	90,000	3,400	60,000	2,500	33,000	750
March 7	35	3.8	430,000	3,400	30,000	190	140,000	2,300	75,000	1,500	40,000	70
14	38	3.1	500,000	18,000	35,000	700	170,000	5,500	120,000	4,500	25,000	550
21	38	3.0	600,000	7,500	65,000	320	180,000	2,200	140,000	1,800	55,000	360
28	42	2.5	460,000	18,000	36,000	500	140,000	5,700	95,000	4,500	25,000	700
April 4	40	3.2	450,000	8,000	60,000	1,400	140,000	3,000	80,000	2,200	40,000	240
11	42	2.4	2,500,000	37,000	500,000	6,000	160,000	8,500	90,000	4,400	10,000	1,000
18	42	1.7	1,100,000	35,000	220,000	6,000	160,000	4,300	75,000	2,000	70,000	850
25	46	2.7	600,000	100,000	70,000	2,400	150,000	7,500	75,000	2,300	46,000	800
May 2	54	3.4	450,000	2,000	60,000	200	250,000	1,000	55,000	300	55,000	55
9	48	3.1	600,000	23,000	180,000	5,500	210,000	2,200	140,000	900	25,000	400
16	56	3.0	600,000	9,000	85,000	1,200	120,000	1,800	32,000	1,600	40,000	200
23	58	2.6	1,400,000	28,000	220,000	2,400	280,000	11,000	170,000	9,000	85,000	1,000
30	62	2.7	700,000	18,000	130,000	3,800	230,000	6,000	160,000	350	64,000	800
June 6	61	2.8	850,000	34,000	100,000	3,800	190,000	4,600	150,000	3,500	85,000	850
13	68	2.5	550,000	35,000	160,000	1,500	75,000	3,200	55,000	1,500	40,000	200
20	68	2.8	630,000	32,000	120,000	3,600	110,000	4,800	60,000	1,500	8,000	62
27	68	3.0	1,100,000	13,000	120,000	1,300	210,000	5,700	50,000	300	2,800	200
Average	45	3.4	750,000	24,000	95,000	1,800	150,000	3,900	90,000	2,400	47,000	380

[a] Jackson bile media used.

The average efficiencies as measured by the per cent of bacteria removed for the whole period and for certain shorter periods, selected to illustrate the effect of different concentrations of chlorine and of fluctuating conditions of temperature, are shown in Table 18.

TABLE 18.—*Disinfection of trickling-filter effluent at Boston; summary of bacteriological results, averaged by periods, to show the effect of changes in temperature and in the amount of available chlorine.*

Period.	Temperature.	Available chlorine, in parts per million.	Per cent of bacteria removed.				
			Bacteria at 20° C.		Bacteria at 37° C.		
			Total.	Liquefiers.	Total.	Acid formers.	*B. coli.*
	° *F.*						
November 12 to June 27	45	3.4	96.8	98.1	97.4	97.3	99.19
November 12 to December 12	42	6.3	99.57	99.73	99.81	99.91	99.99
January 27 to March 28	36	3.2	95.8	97.7	96.6	96.4	98.5
April 27 to June 27	60	2.9	97.1	98.0	97.6	97.9	99.07

Comparison of the results obtained in the periods November 12 to December 12 and January 27 to March 28 shows that the additional bacterial removal gained by increasing the available chlorine from 3.2 to 6.3 parts per million, although it is considerable in amount, is hardly commensurate with the cost. The effect of temperature on the bacterial removal is shown in the periods from January 27 to March 28 and April 27 to June 27. The mean temperature is 36° F. in one period and 60° F. in the other, while the available chlorine is practically the same in both periods, though slightly higher during the period of lower temperature. An advantage in favor of the summer results is noticeable, and it would probably have been a little greater with exactly the same amount of chlorine. Yet the results show especially that the effect of temperature on efficiency is not great. This point is of special significance in comparing the results of chlorine disinfection with those obtained with copper. In experiments with copper, temperature has been shown to produce a marked effect; in fact, the concentration of copper must be doubled during the winter months to maintain the efficiency of the process. The bacterial removals in the several groups of bacteria recorded are nearly the same, though the removal of *B. coli* is higher in all experiments. It is probably safe to assume that the removal of the typhoid and other pathogenic organisms will be as nearly perfect as the removal noted in any of these groups. The per cent removals of organisms shown by the counts at 37° C. and by the *B. coli* results probably represent most nearly the per cent removal of typhoid bacilli.

As has been stated, the reliability of a disinfection process depends quite as much on the general evenness of the results as on the average efficiency. For that reason the per cent removal of total bacteria has been computed for each of the 158 individual tests, and the results of the calculations, given in Table 19, show that the per cent removal was between 98 and 100 per cent in over half the individual tests, and that it was less than 94 per cent in only 15 per cent of the tests.

TABLE 19.—*Relation between individual tests of bacterial removal and the average result at Boston.*

Per cent of total number of tests.[a]	Per cent removal of total bacteria.	
	Not less than—	Less than—
54	98	100
19	96	98
12	94	96
6	92	94
2	90	92
3	85	90
2	75	85
2	65	75
Total, 100	Average, 96.3	

[a] Number of individual tests, 158.

The number of bacteria remaining in the disinfected effluent have been tabulated in a similar manner, in order that the bacterial quality of the final effluent may be properly understood. The results are given in Table 20.

TABLE 20.—*Relation between individual bacterial counts and the average result at Boston.*

Per cent of total number of tests.[a]	Total number of bacteria per cubic centimeter.	
	Not less than—	Less than—
47	100	10,000
23	10,000	25,000
20	25,000	50,000
5	50,000	100,000
3	100,000	200,000
2	200,000	250,000
Total, 100	Average, 24,000	

[a] Total number of tests, 158.

The average of the 158 individual tests of bacterial removal is 96.3 per cent, as compared with 96.8 per cent removal (see Table 17, p. 42) obtained from the average numbers for the whole period. The first figure is more nearly correct for estimating the efficiency of the process; but it is evident that the last figure, which is more commonly employed in such work, gives the average result with sufficient accuracy. The somewhat tedious calculation of the individual results

l their variations has been made only for the total bacteria; but
results suffice to show that the average per cent removal of bac-
ia, computed from the average initial and final counts, is practically
same as the average of the per cents calculated from the individual
ts, and that there is a certain variation in the results to the extent
own. As to the other groups of bacteria studied, it is sufficient to
te that similar computations with them gave practically identical
sults, subject to much the same deviations.

In order to study the effect of varying the time of contact with the
sinfectant, samples of the trickling-filter effluent were collected from
e mixing trough after the disinfecting solution had been added.
ter these samples had been well shaken, determinations were made
the number of bacteria remaining at the end of ten minutes, fifteen
inutes, one hour, and two hours, the sample being shaken each time
fore withdrawing the test portion. The number of bacteria in the
fluent before treatment, as determined on a separate sample, was
etween 250,000 and 1,000,000 per cubic centimeter; but the num-
ers in all tests have been converted to a uniform basis of 1,000,000
itial bacteria per cubic centimeter for more ready comparison of the
esults in Table 21.

ABLE 21.—*Relation between time of contact and efficiency of disinfection with chloride of lime.*[a]

Date.	Number of remaining bacteria per cubic centimeter[b] after contact for—			
	10 minutes.	15 minutes.	60 minutes.	120 minutes.
ugust 6	....	1,100	160	150
9	2,500	190	58	7
10	10,000	270	....	40
11	3,500	570	154	100
14	47,000	1,100	700	570
15	4,200	310	120	120
16	1,200	240	160	130
17	9,800	800	260	150
20	400,000	12,000	7,000	5,500
21	28,000	2,100	1,300	1,000
23	1,300	230	110	31
Average	50,000	1,700	950	700
Per cent of remaining bacteria	5.0	0.17	0.10	0.07

[a] Available chlorine, 5 parts per million.
[b] All numbers converted to a uniform basis of 1,000,000 initial bacteria per cubic centimeter.

The rapidity of the action of the disinfectant is somewhat surprising, and it indicates that long periods of contact are unnecessary. It is evident that the greater part of the disinfection is accomplished within the first fifteen minutes, and that a contact period of one hour is probably ample for practical work. Another feature of interest in this experiment is its bearing on the character of the sediment in the disinfection tanks. It has been suggested that perhaps such sediment carries down with it large numbers of the bacteria that are recorded as being removed, though they may be still vigorous with the protecting body of solid matter. It is undoubtedly true that ordinary sedimentation tanks remove a considerable number of bacteria, and the actual removal is doubtless even greater than wou appear from the data, owing to multiplication during sedimentati But in their slow descent through the liquid, such bacteria are subjec to the action of the chlorine, the supply of which is constantly renewe by the downward movement of the particles. The major portion o such sediment is suspended in the liquid for periods varying fro fifteen minutes to an hour, during which time the chlorine has evidently ample opportunity to act. In the series of tests jus described this sediment was included in the bacterial determination It is interesting to note, therefore, that the average reduction o bacteria at the end of two hours was 99.93 per cent, while the routin tests on the same days in the sedimentation tank gave an averag reduction of 99.96 per cent, results practically identical. Th sediment is apparently as completely disinfected as the supernatan liquid, but naturally an accumulation of sediment at the bottom o the tank would soon rid itself of chlorine and permit the multiplication of the remaining bacteria. Such secondary growth of bacteria however, has no sanitary significance, since it has been satisfactori shown that the pathogens do not develop in such manner outside the body.

These results demonstrate the entire feasibility of satisfactorily disinfecting trickling-filter effluents with chloride of lime, and they indicate that about 3.5 parts per million of available chlorine and a contact period of about one hour are ample for an effluent like that on which the experiments were made. A general discussion of the results in their practical application to the disinfection problem with special reference to costs is given on pages 63–70.

DISINFECTION OF CRUDE SEWAGE.

Under certain circumstances it may be necessary and desirable to disinfect the crude sewage of a community, though such a procedure would not as a rule be considered. It can never take the place of purification except by the use of excessive amounts of disinfectant and by destroying the bacteria always present it simply delays the natural processes of reduction, allowing them to proceed at a later time, possibly after the solid matter has had time to settle to the bottom of a stream where the greatest nuisance will be caused by its decomposition. It might happen, however, that a sufficiently great dilution to preclude anaërobic action and a sufficiently swift current or tidal flow to prevent sedimentation would obviate all danger of a nuisance except from a bacterial standpoint. Such conditions are, erhaps, most nearly realized in our seaboard cities, where there may e no question of a physical nuisance, but where bacterial pollution the harbor waters may be undesirable for various reasons.

The disinfection of crude sewage was studied because it was elieved that experiments with the material might help to solve the eneral problem. The relations between available chlorine, mount of organic matter, and germicidal effect suggest that an xcessive amount of organic matter in raw sewage might affect the fficiency of the chloride of lime treatment by combining directly ith the chlorine and thus preventing its activity. The quality of e organic matter might also influence the result; for, as the organic atter of crude sewage is more readily oxidizable than that of an ffluent, it might be expected to consume a greater amount of chlorine han the latter in a short time. The experiments with crude sewage vere undertaken with the object of studying such features and of scertaining the concentrations of chlorine necessary to effect a atisfactory removal of the bacteria in crude sewage, having in view oth the possible disinfection of crude sewage itself and the establishment of a maximum limit of available chlorine in the treatment of effluents.

The details of these experiments differ somewhat from those of the effluent tests that have been described. In treating an effluent, sedimentation is an advantageous process by itself and can be usefully employed as an adjunct in disinfection, but in treating raw sewage, the removal by sedimentation of large amounts of organic matter in an unoxidized condition is undesirable and is not permissible in practice. In the experimental work, therefore, it was necessary to prevent sedimentation during the treatment.

A rectangular tank having a capacity of about 700 gallons was employed for the experiments. A 2-inch pipe led from the bottom of the tank to a pump with sufficient capacity to draw out the entire contents of the tank in half an hour. The outlet pipe from the pump discharged into the top of the tank, and the rapid circulation maintained in the sewage in this manner during the experiment made sedimentation of solids practically impossible. Before the beginning of the test the sewage was pumped through the system for fifteen minutes in order to insure thorough mixing; then a sample was collected for chemical and bacterial analysis, and the calculated amount of disinfectant solution was slowly poured into the inflowing stream. The force of this stream entering the tank from a height of about six feet churned the sewage thoroughly and assured rapid and complete mixing. Samples were collected at the end of the second and fourth hours for determination of the total bacteria growing at 20° C. and of the number of *B. coli*. The available chlorine employed was ten parts per million. In the first series of tests the total amount of chloride of lime was added at first, but in the second series it was added in four portions at hourly intervals. The results are tabulated in Table 22.

TABLE 22.—*Disinfection of crude sewage with chloride of lime at Boston; series 1 and 2.*[a]

Series.[b]	Temperature.	Number of bacteria per cubic centimeter.		
		Initial.	At end of 2 hours.	At end of 4 hours.
	°F.			
1	44	700,000	4,900	13,000
	46	260,000	220	5,700
	50	750,000	10	100
	60	600,000	620	80
	60	200,000	500	100
	60	270,000	500	100
Average	54	460,000	1,100	3,400
2	56	600,000	700	190
	60	460,000	100	60
	60	360,000	260	40
	60	460,000	14,000	340
	60	280,000	22,000	200
	60	540,000	7,000	130
Average	59	450,000	7,500	160
Number of *B. coli* per cubic centimeter; average of both series		35,000	24	15

[a] Available chlorine, 10 parts per million.
[b] Series 1. Chlorine added at start. Series 2. Chlorine added in four equal hourly portions.

The average reduction of total bacteria in the first series was 99.76 per cent at the end of two hours, and, owing to multiplication of bacteria, 99.26 per cent at the end of four hours. In the second series the reduction in two hours was only 98.3 per cent, five parts per million of available chlorine having been added up to that time, and the addition of another five parts of chlorine brought the total reduction up to 99.96 per cent at the end of four hours. This indicates that there is a distinct advantage in adding the disinfectant in successive portions, but the increased efficiency in this case was not great, and it is doubtful whether it would generally be sufficient to compensate for the more complicated method of operation.

The figures for *B. coli* have little individual significance, but the average values indicate a removal of *B. coli* of 99.93 per cent and 99.97 per cent after two hours and four hours, respectively—values that are considerably better than those derived for the total bacteria. The results of the disinfection of crude sewage therefore agree with those obtained with the filter effluent. It is also apparent from these experiments that ten parts per million of available chlorine are ample to disinfect the crude sewage of Boston, and it is probable that even a less concentration would give satisfactory results. It is evident also that two hours is a sufficient contact period, little advantage being gained by making it longer.

In April, 1908, a third series of experiments with crude sewage vas made to determine the minimum amount of chlorine and of conact time possible for satisfactory disinfection. These tests were ssentially like those of the first series, except that the available hlorine was varied each day, so that on successive days it amounted o two, four, six, eight, and ten parts per million, respectively. On he sixth day it was started again at two parts. In this way the ffect of chlorine concentration was studied with as little interference s possible from other variables, such as temperature and character f the sewage. A two-hour period of contact was given, and in addition to the initial sample, in each test, samples were collected after half an hour, one hour, and two hours. The results of this series are shown in Table 23.

TABLE 23.—*Disinfection of crude sewage with chloride of lime at Boston; series 3.*

Available chlorine (in parts per million).	Temperature.	Number of bacteria per cubic centimeter.			
		Initial.	One-half hour.	1 hour.	2 hours.
	° F.				
2	52	1,100,000	90,000	62,000	130,000
	58	1,600,000	320,000	470,000	870,000
	59	1,200,000	32,000	49,000	140,000
	53	900,000	47,000	16,000	42,000
	60	1,900,000	400,000	450,000	700,000
	64	1,700,000	370,000	460,000	1,000,000
4	54	2,100,000	50,000	41,000	65,000
	55	1,100,000	5,000	6,500	4,400
	59	1,400,000	30,000	40,000	85,000
	58	950,000	3,400	1,100	4,200
	60	1,900,000	12,000	11,000	23,000
	64	3,500,000	33,000	26,000	80,000
6	56	1,700,000	3,600	9,000	1,700
	58	1,700,000	6,500	600	6,000
	60	2,800,000	17,000	4,600	4,400
	57	1,700,000	1,700	8,400	3,900
	60	2,400,000	1,800	3,000	1,700
	64	3,300,000	14,000	11,000	18,000
8	55	1,600,000	570	480	600
	60	1,500,000	3,400	160	730
	59	2,000,000	2,000	1,100	3,700
	59	1,100,000	340	170	750
	63	2,600,000	1,900	2,700	3,300
	65	2,500,000	6,300	3,300	9,500
10	52	1,600,000	380	300	400
	57	610,000	200	210	200
	58	1,900,000	1,100	430	1,600
	62	1,100,000	350	800	1,100
	64	2,500,000	500	350	850
	64	3,100,000	3,500	2,300	4,800
Control	56	1,200,000	1,500,000	1,800,000	2,100,000

The results indicate that a large amount of chlorine is consumed by the sewage within two hours. Two parts per million are consumed within half an hour and ten parts per million are not sufficient to prevent the subsequent growth of bacteria. It has, however, already been pointed out that such subsequent growths have no significance and that the efficiency of the disinfection from the standpoint of the pathogenicity of the sewage is measured by the maximum reduction, independent of any subsequent increase.

The average initial and minimum figures and the per cent of bacteria removed for each concentration of chlorine are brought together in Table 24.

TABLE 24.—*Disinfection of crude sewage with chloride of lime at Boston; summary of results.*

Available chlorine (in parts per million).	Average number of bacteria per cubic centimeter.		Bacteria removed.
	Average initial.	Average minimum.	
			Per cent.
2	1,400,000	210,000	85
4	1,800,000	23,000	98.7
6	2,200,000	6,000	99.7
8	1,900,000	1,200	99.94
10	1,800,000	700	99.96

These experiments were not sufficiently prolonged to furnish complete data on the process, and it is not at all unlikely that at another season of the year somewhat different results might have been obtained, though it has been shown in connection with the work on effluents that the temperature effect on the disinfection itself, other conditions remaining constant, is but slight. The bacterial and chemical composition of crude sewage, however, is affected by temperature to a much greater extent than is that of filter effluents. The amount of dissolved oxygen present is an important index to the character of the sewage or the effluent in reference to its effect on chlorine; absence of dissolved oxygen in particular indicates ready oxidizability, which in turn means the rapid absorption of chlorine. It is probably true that a given amount of chlorine acting for a given time will bring about a definite reduction in the total number of bacteria, regardless of the character of the treated liquid. Unless excessive amounts of chlorine are added, however, the time of contact is determined by the character and the amount of the organic matter in the sewage; consequently the more rapidly the chlorine is exhausted by this organic matter the shorter is the time of contact and the less is the bacterial reduction. The sewage experimented with in these tests represents about an average condition in regard to reducibility, and it contained about one-half the amount of dissolved oxygen that would be found during the winter months. Results fully as satisfactory as these could doubtless be obtained during six months of the year with even less available chlorine. During the summer months, when dissolved oxygen is not present, more chlorine than is here indicated would be found necessary. The Red Bank experiments on septic sewage make it probable that a concentration of ten parts per million of available chlorine may be taken as a maximum amount during the summer.

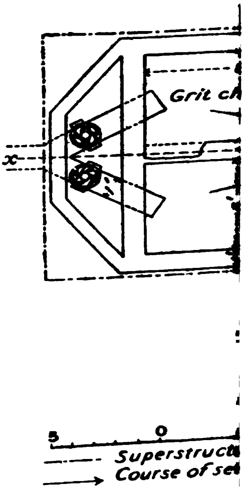
Satisfactory disinfection of crude Boston sewage can be accomplished by adding chloride of lime in such amounts that the available chlorine will amount to about five parts per million during six months of the year, and to between five and ten parts during the other six months, or an average amount during the year of seven or eight parts per million. The addition of the disinfectant in portions at intervals during the treatment yields results that are somewhat better than those obtained by adding the entire amount at once, but it is not probable that this advantage is commensurate with the additional complications involved.

DISINFECTION OF SEPTIC SEWAGE AT RED BANK, N. J.

The successful results obtained in the disinfection of trickling-filter effluents at Boston in 1906 warranted the extension of the experiments to include a practical demonstration; and that step was made possible through the cooperation of the New Jersey State Sewerage Commission. Red Bank, a town of about 6,500 inhabitants, situated on Navesink River in Monmouth County, was selected for the tests for two reasons: The works at Red Bank were so arranged that the experiment could be undertaken at a minimum expense for new construction; and, like many other communities in that section of the State, the town was discharging partly-purified sewage into waters that shortly reached important shellfish areas. A septic sewage of rather poor quality was to be treated. Work with an effluent of higher grade had been desired, but the novelty of treating a septic sewage and the immediate practical value of the results promised to make this experiment well worth undertaking. The conditions resembled those described on pages 12–13, where it was suggested that in certain localities thorough disinfection of crude or septic sewage will go far toward accomplishing all that is needful. At least the most necessary step is thus taken first, and it is a logical first step in the gradual improvement of sanitary and economic conditions along our water fronts.

It was realized that more chloride of lime would be needed than had been used in previous experiments, but how much more was not known. The Boston results with crude sewage were not available at that time, and it was to be expected that, owing to the highly unstable character of septic sewage, even more chloride of lime would be necessary than for crude sewage. The work was started in October, 1906. During the fall the disinfection apparatus was left to the care of a local attendant, and a representative of the commission visited the works twice a week to collect samples for analysis; but mechanical deficiencies in the dosing device led to intermittent and irregular dosing, so that the results obtained were far from satisfactory, and considerable time was consumed before it was learned that more than 10 parts per million of available chlorine would be required. The work was discontinued when cold weather began, but it was resumed under more favorable circumstances in the summer of 1907. A laboratory in charge of Mr. Daniels was installed at the works, and the entire experiment was then under careful observation, for samples could be taken and examined as frequently as might be desired. The results amply justified this course. The earlier work indicated the probable strength of chlorine necessary, and developed many defects and weaknesses in the dosing apparatus, all of which were remedied. The investigations that were conducted during the summer of 1907 only are reported.

The sewerage system of Red Bank is constructed on the separate plan, with special drains to carry off rain water. On account of the sandy nature of the soil and the poor construction of the sewers considerable storm water finds its way into the sewers. The average dry-weather flow of sewage is about 265,000 gallons a day. The following description of the disposal works will be more readily understood by referring to Plate I. After entering the works the sewage divides into two streams, passing through two grit chambers each 5 by 8 feet in plan and 3 feet deep to the flow line. The flow may be entirely diverted through either tank to allow the other t be cleaned out. From these chambers the sewage flows to the septic tank, which is circular in plan, 43 feet in diameter, with a normal depth to the flow line of 8 feet 6 inches at the periphery and 5 feet at the center, the bottom being conical. Its capacity at that depth is about 82,000 gallons, or approximately an 8-hour dry-weather flow. For the purpose of these experiments, however, it was necessary to raise the flow line throughout the system 1 foot, a change that increased the capacity of the tank to about 93,000 gallons. At the side of the tank opposite the entrance pipe the septic sewage passes out through a submerged 12-inch pipe *i*, which later divides into a Y. A branch then runs downward to the bottom of each of the filters, thence horizontally to a point beneath the center, thence upward into the filter, as shown in the sectional view. The so-called filters are two in number, and each is 12 feet in diameter. Tank *a* is 9 feet deep to the flow line, with a capacity of 7,600 gallons, and tank *b* is 8 feet 3 inches deep, with a capacity of 7,000 gallons. The tanks were originally filled with stone and brick over a false bottom and were practically strainers for the removal of suspended matter. Each filter is provided with a 12-inch overflow leading to a manhole outside the building. For these experiments the filtering material was entirely removed from both tanks, one of the outlets was closed, and a cross-connection was put in to conduct the sewage from the top of the first tank to the bottom of the second. By closing the inlet valve of the latter the entire flow was made to pass through the two tanks in series. Suitable baffles were provided, as indicated in the plan, so that the entire capacity of the tanks could be utilized to the best advantage. As thus arranged, each tank held about forty-five minutes' flow, and the efficiency of the process was tested t the end of forty-five minutes and ninety minutes.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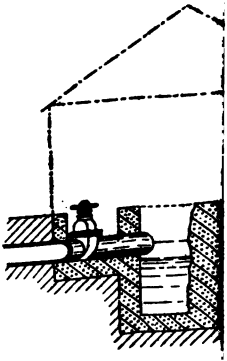

Chloride of lime was used throughout the work. For the preparaion of the solution two hogsheads *c* and *d* of about 240 gallons capacity each were provided, one elevated over the other. In the upper hogshead the requisite amount of bleaching powder was mixed with water and allowed to settle over night. The next morning the clear supernatant liquid was drawn into the lower hogshead. The atter was connected directly with a constant-level tank *e*, controlled by a ball cock, on which a glass ball and special fittings were necessary to prevent corrosion. The constant-level tank was connected by a flexible rubber tube with the dosing tank *f*—a box 6 by 6 inches in plan and 8 inches deep—provided with a three-sixteenth-inch orifice in one side and suspended on one end of a 6-foot lever *g*, the other end of which was connected with a large float *h* in tank *a*. Tank *a* was provided at its outlet with a 1-foot weir, by which the water level was made to vary with the flow. An increase in the flow increased the elevation of sewage in the tank, thus raising float *h* and lowering the suspended box *f* at the other end of the lever. Since box *f* was connected with the constant-level tank *e*, the effect of such change was virtually to increase the head over the orifice. In this manner the flow of the hypochlorite solution was automatically kept about proportional to the flow of sewage. The ratio was not exact, because the variation in flow with the head is not the same with a weir as with an orifice, but within the range of flows used the arrangement was quite satisfactory. By discharging the sewage from tank *a* through a submerged pipe instead of over a weir the ratio between the two flows could be kept the same at all heads. A suitable gage was erected in tank *a*, and the elevation of the sewage over the weir crest was recorded at intervals of two hours from 6 a. m. to 6 p. m., or more frequently during storms. These readings were converted into gallons, and the daily discharges of sewage were calculated from them. The night flow was approximately determined by calculations based on two sets of hourly observations extending over twenty-four hours and on the relation of these sets of data to the general averages of day flows. When the weir gage was read, readings were also taken of a gage in the hogshead *c*, calibrated to read directly in gallons. By this means the hourly flows of disinfectant solution were known at all times and could be compared with the corresponding sewage flows.

The solution of bleaching powder was run into the septic tank outlet pipe *i*, where it mixed with the main flow of sewage. The treated sewage then passed through the two disinfecting tanks *a* and *b* and was finally discharged into the river. The extraction of the hypochlorite was not complete in the one leaching given it. In mills where large quantities of it are extracted three successive lixiviations are customary in order to complete the extraction, but such practice was not feasible here, and the sludge remaining each day in hogshead *d* was dumped into tank *a*, where it settled to the bottom and was slowly leached out by the sewage. In this way all the available chlorine was utilized.

It was necessary to have some information about the chemical composition of the septic sewage under treatment and to make certain chemical tests of the effluent. For this purpose samples of the septic sewage and of the disinfected effluent were collected daily and determinations of the oxygen consumed were made on them. These estimates gave a comparative indication of the strength of the sewage from day to day. Daily determinations of dissolved oxygen in the final effluent were also made, and the effluent was tested for free chlorine. The septic sewage never contained any dissolved oxygen, and under normal conditions the effluent would be in the same condition, but the application of free chlorine to sewage gives rise to chemical reactions, whereby free oxygen is formed. This is largely consumed in the oxidation of the organic matter, but nevertheless some free dissolved oxygen was always found in the effluent. The presence of this oxygen is of great value in the further self-purification of the sewage after reaching the river. Free chlorine was never found in the final effluent. Its presence would be highly injurious to fish life, and disinfection processes of this nature must always be so controlled that no injurious chemical can escape into the stream. In addition to the daily determinations just mentioned, composite sterilized samples were preserved and sent to Boston regularly, where they were submitted to complete chemical analysis. Regular chemical analyses of the bleaching powder and daily assays of the disinfectant solution were made.

The results of the work at Red Bank are given in the form of weekly averages in Table 25, and the relation between the individual and the average results are shown in Table 26.

TABLE 25.—*Disinfection of septic sewage with chloride of lime at Red Bank, N. J.; weekly averages.*

Week ending.	Available chlorine in parts per million.	Total number of bacteria per cubic centimeter at 20° C.			Number of B. coli per cubic centimeter.[a]		
		Initial.	At end of 45 minutes.	At end of 90 minutes.	Initial.	At end of 45 minutes.	At end of 90 minutes.
1907.							
July 20	9.9	800,000	410	460	46,000	4	4
27	10.6	650,000	800	420	80,000	13	11
Aug. 3	11.5	1,800,000	550	130	40,000	21	5
10	11.4	850,000	240	140	55,000	14	2
17	13.0	760,000	2,100	1,500	70,000	30	28
24	7.3	700,000	45,000	55,000	70,000	700	600
31	7.5	1,200,000	45,000	26,000	220,000	16,000	2,000
Sept. 14	11.8	750,000	13,000	8,000	300,000	150	140
21	13.1	750,000	850	800	500,000	270	260
28	10.5	700,000	120	88	550,000	80	28
Average[b]	11.5	900,000	2,300	1,400	205,000	75	60

[a] Jackson bile media used.

[b] Exclusive of period August 19–31; temperature 56° to 58° throughout.

TABLE 26.—*Relation between individual tests of bacterial removal and the average result at Red Bank, N. J.*

Per cent of total number of tests.[a]	Total number of bacteria per cubic centimeter.	
	Not less than—	Less than—
84	100	1,000
5	1,000	2,000
5	2,000	5,000
6	5,000	.....
Total, 100	Average, 1,900	

[a] Total number of tests, 224.

During the period August 19 to August 31, the available chlorine was reduced to about 7.5 parts per million. A removal of the total bacteria amounting to about 95 per cent and of *B. coli* amounting to 94.3 per cent after three-quarters of an hour and 99 per cent after one and a half hours was obtained, but the individual results were very erratic, and it was apparent that an insufficient amount of chlorine was being added. The chlorine was therefore increased again to about 12 parts per million and kept there during the remainder of the experiment. The averages in the last line of Table 25 do not include the results for the above-mentioned period. The average per cent removal of total bacteria was 99.7 at the end of 45 minutes, and the corresponding *B. coli* figure is 99.96. In 90 minutes the average per cent removals were 99.8 and 99.97, respectively. It is rather striking that such results can be obtained with 12 parts per million of available chlorine, while the results are poorer and very erratic with 7.5 parts. The explanation is probably found in the character of the sewage, which was very concentrated in its raw state and had passed through a septic tank that was working vigorously. A large amount of hydrogen sulphide was contained in the septic sewage. The characteristic odor of this substance was extremely noticeable in the vicinity of the works, and the addition of chlorine to the sewage produced a milkiness, due to the liberation of free sulphur. Titration of the septic sewage in the cold with potassium permanganate, a substance less easily reduced than chlorine, indicated that enough hydrogen sulphide and other easily oxidizable substances were present to reduce instantly about five or six parts per million of chlorine. Consequently the efficient results in this experiment were in reality obtained with about six parts of available chlorine and the poor ones with about three parts.

The disinfection of septic sewage evidently requires so much chlorine that the expense will be considerable. It will probably be found to take twice as much chlorine for septic sewage as for the corresponding crude sewage. The combination of septic action and disinfection eliminates the suspended matter and the bacteria from the sewage and in many localities would constitute a very desirable system. In practice, however, the order of the processes should be reversed. The disinfection of the crude sewage can be done in a small tank of an hour's capacity. The disinfectant should be so regulated that little or no chlorine would flow into the septic tank. Unless a considerable amount of chlorine should thus escape at one time there would be no objectionable effect on the action in the tank. There would be a great multiplication of bacteria in the tank, so that the number in the final effluent would probably be as great as in the raw sewage, and perhaps even greater. Nevertheless, the disinfection would be as effective on the pathogens as if it were applied as a final process. The subsequent development of saprophytes would have no sanitary significance and would doubtless be of real value in the subsequent self-purification of the organic matter after it had been discharged into the stream.

DISINFECTION OF TRICKLING-FILTER EFFLUENT AT BALTIMORE.

Reference was made in the history of the experiments to the cooperative arrangement between the United States Geological Survey and the Baltimore sewerage commission. In December, 1907, the sewerage commission undertook a study of disinfection methods at its Walbrook testing plant. The writer assisted in planning this work, and was consulted from time to time during its progress. The disinfection experiments were made a part of the routine work of the testing station, and they were carried out by the station staff. A complete review of this investigation, the most important and most comprehensive one on the subject ever conducted, will, it is hoped, be made by the sewerage commission in the near future. The present report has been made as brief as possible and includes only the work done before June 30, 1908.

The Walbrook testing plant, in the extreme western section of Baltimore, was built for use in investigating certain problems in connection with the disposal works now being built at Back River, the main features of which—screening, sedimentation, treatment on trickling filters, and final sedimentation—had already been decided upon. Information was specially desired as to the probable bacterial efficiency of such a process and as to the necessity for further treatment of the effluent, because the statutes of the State of Maryland require rather high bacterial efficiency. As a detailed description of the testing plant has already been published,[a] it is sufficient to state that a small section of the city was sewered and that sewage amount-to about 50,000 gallons a day was brought to the plant and ated by a system comprising a grit chamber, a septic tank, trick- g filters, and sedimentation tanks. Trickling filters of several pths and sizes of material are employed. The sewage is rather onger than ordinary city sewage and is very fresh. The effluent ed in the disinfection studies came from a filter 12 feet deep, built crushed stone ranging in size from 0.5 inch to 1.5 inches. The rate filtration fluctuated with the flow of sewage, but it averaged about 000,000 gallons an acre a day. The effluent was conducted to a dimentation basin designed to give a two hours' flow. The disin- ctant employed throughout this investigation was chloride of lime, ssolved and added to the effluent in practically the same manner at Boston, as the effluent left the filter drain. The disinfecting lution and the effluent mixed during the short flow through a pipe the sedimentation basin.

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[a] Eng. News, vol. 57, 1907, p. 235.

Monthly averages of the analyses of this effluent as it left the filter nd after disinfection and sedimentation are given in Table 27.

ABLE 27.—*Chemical analyses of trickling-filter effluent at Baltimore before and after disinfection with chloride of lime and sedimentation; monthly averages.*

[Parts per million.]

INITIAL.

Month.	Suspended solids.		Organic matter.		Nitrogen as—			Oxygen consumed.[a]
	Total.	Loss on ignition.	Total.	Solids.	Free ammonia.	Nitrites.	Nitrates.	
1908.								
January	56	35	8.3	5.9	7.4	0.48	17	16
February	38	25	8.0	6.8	6.8	.13	17	17
March	53	31	8.9	7.5	5.5	.30	19	16
April	42	28	10.0	9.0	7.5	.08	21	18
June	33	21	7.0	6.5	4.0	.40	20	13
Average	45	28	8.4	7.1	6.2	.28	19	16

FINAL.

Month.	Suspended solids.		Organic matter.		Nitrogen as—			Oxygen consumed.[a]
	Total.	Loss on ignition.	Total.	Solids.	Free ammonia.	Nitrites.	Nitrates.	
1908.								
January	38	26	8.5	6.2	7.2	0.49	16	15
February	25	17	6.8	5.8	6.8	.12	17	17
March	26	17	7.9	7.1	5.5	.19	20	15
April	34	20	9.6	7.6	7.9	.08	22	18
June	21	16	7.0	6.5	4.0	.25	20	13
Average	29	19	8.0	6.6	6.3	.23	19	16

[a] Thirty-minute boiling method.

Initial and final bacteriological samples were collected as usual. Bacterial counts were made three times a day for five days each week and twice on Saturday. *B. coli* determinations were made twice daily. The results are shown in Tables 28, 29, and 30. Table 28 gives the average weekly results; Table 29 shows the relation between the removal of bacteria in individual samples and the average removal; Table 30 indicates the relation between the number of bacteria in the individual samples and the average number.

TABLE 28.—*Disinfection of trickling-filter effluent with chloride of lime at Baltimore; weekly averages.*

Week ending—	Temperature.	Available chlorine (parts per million).		Total number of bacteria per cubic centimeter at 20° C.		Total number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter at 37° C.		Number of B. coli per cubic centimeter.[a]	
		Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final
1908.	° *F.*										
Jan. 4	50	3.5	......	170,000	1,600	70,000	600	8,000	107	3,800	59
11	45	2.0	......	90,000	6,500	5,500	200	3,000	58	1,700	380
18	48	1.9	......	120,000	3,300	3,100	250	2,200	165	3,400	240
25	47	2.0	......	160,000	1,900	2,000	95	900	8	1,300	45
Feb. 1	40	2.6	1.3	120,000	2,200	1,900	73	950	4	2,000	490
8	43	2.5	1.1	70,000	4,100	1,000	70	400	4	600	470
15	46	0.94	0.1	80,000	11,000	1,500	400	700	90	440	330
22	45	1.4	0.4	65,000	20,000	4,000	440	3,000	180	750	70
29	45	1.5	0.4	100,000	4,600	3,000	100	1,100	17	2,400	210
Mar. 7	46	2.0	0.6	80,000	1,000	1,400	80	900	2	1,600	150
14	47	1.7	0.4	80,000	1,700	1,000	60	500	3	1,400	180
21	49	2.0	0.4	100,000	1,300	1,100	80	600	15	2,600	180
28	52	2.1	0.3	150,000	1,700	2,400	160	1,500	3	800	210
Apr. 4	50	1.7	0.4	120,000	1,800	4,100	120	2,100	10	2,100	220
11	55	2.6	1.1	140,000	1,100	2,800	70	1,900	2	3,700	39
18	54	2.2	0.6	120,000	2,500	13,000	110	3,600	25	5,500	55
25	56	2.6	0.3	120,000	2,100	18,000	350	7,000	110	2,200	200
May 2	58	3.1	......	130,000	1,200	3,500	110	2,400	3	1,400	130
9	56	2.8	1.0	160,000	2,300	2,200	70	1,600	9	1,800	43
June 13	66	2.3	0.4	120,000	17,000	21,000	3,600	9,500	[b]730	600	100
20	67	2.3	0.8	115,000	1,300	1,800	440	300	18	3,000	300
27	67	1.9	0.1	190,000	3,700	2,900	1,100	430	0	800	400
Average	51	2.2	0.6	120,000	4,300	7,500	390	2,400	70	2,000	200

[a] Jackson bile media used.

[b] High average due to one count of 8,000.

TABLE 29.—*Relation between individual tests of bacterial removal and the average result at Baltimore.*

Per cent of total tests.[a]	Per cent of bacterial removal.	
	Not less than—	Less than—
69	98	100
14	96	98
6	94	96
0	92	94
2	90	92
2	85	90
4	75	85
1	65	75
1	40	65
1	..	40
Total, 100.	Average, 95.5.	

[a] Total number of tests, 255.

TABLE 30.—*Relation between individual bacterial counts and the average result at Baltimore.*

Per cent of total tests.[a]	Number of bacteria per cubic centimeter.	
	Not less than—	Less than—
36	100	1,000
35	1,000	2,000
8	2,000	3,000
3	3,000	4,000
4	4,000	5,000
2	5,000	6,000
2	6,000	8,000
3	8,000	10,000
7	10,000	......
Total, 100.	Average, 4,300.	

[a] Total number of tests, 255.

The average of the individual bacterial removals is 95.5 per cent. The per cent removal calculated from the average numbers in Table 28 is 96.6 per cent. The average efficiency, as in the Boston experiments, may be expressed in the latter form with sufficient accuracy, and this shorter method is employed in the other bacterial computations, by which the efficiencies in Table 31 were obtained.

TABLE 31.—*Average bacterial removal during the disinfection of trickling-filter effluent at Baltimore.*

	Per cent.
Total bacteria at 20° C	96.6
Total bacteria at 37° C	94.9
Acid formers at 37° C	97.0
B. coli [a]	90.0

The average results agree practically with those obtained at Boston. The trickling-filter effluent at Baltimore was of better quality than that at Boston and less chlorine was used. The average amount of available chlorine was 2.2 parts per million, as compared with 3.4 parts at Boston. Though the average reduction of total bacteria at both places was practically the same, the variations were greater at Baltimore, and they indicate that a somewhat greater amount of chlorine would materially improve the results. It is probable that three parts per million of available chlorine are best for treating this effluent. The *B. coli* results are not in harmony with the rest of the figures. In all the work at other places the removal of *B. coli* has been without exception better than the removal of the total organisms. Soon after the beginning of the Baltimore studies it was noticed that the removal of *B. coli*, as indicated by the bile test, was far less perfect than the general results, but efforts to discover the cause of the discrepancy were only partly successful. Complete identification of *B. coli* was carried out for a period, and the results seem to indicate that many of the positive tests after disinfection are due to the presence of an organism other than *B. coli*, which fermented the bile medium. Similar atypical results were obtained in the initial samples, but not in such large proportion. The evidence of other work under the direction of the author indicates that in these experiments the removal of *B. coli* is better shown by the removal of acid-forming bacteria than by the bile test. The results as a whole demonstrate the entire feasibility of the process and the possibility of obtaining practical disinfection at a reasonable cost.

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[a] Jackson bile media used.

COMPARATIVE GERMICIDAL EFFICIENCIES OF CHLORINE AND SOME OF ITS COMPOUNDS.

Only a small amount of accurate data was at hand for the comparison of the germicidal efficiency of chlorine in its various forms. Accordingly, three series of comparative tests were made upon trickling-filter effluents for the purpose of obtaining such information. The results of these studies are collated in Table 32, each figure of which is the average of from three to twelve tests reduced to a uniform basis of one million initial bacteria per cubic centimeter.

TABLE 32.—*Relative germicidal properties of chlorine and some of its compounds.*

[All numbers converted to a uniform basis of 1,000,000 initial bacteria per cubic centimeter.]

Series.	Source of chlorine.	Available chlorine (in parts per million).	Total number of remaining bacteria per cubic centimeter.		
			At end of 30 minutes.	At end of 1 hour.	At end of 2 hours.
I	Free chlorine	3	650	390	280
	Sodium hypochlorite	3	500	270	230
	Potassium hypochlorite	3	410	260	280
	Potassium chlorate	3	800,000	900,000	1,000.000
	Potassium perchlorate	3	750,000	1,400,000	1,800,000
II	Free chlorine	2	17,000	13,000	17,000
	Sodium hypochlorite[a]	2	15,000	6,000	6,000
	....do.[b]	2	4,600	2,100	3,400
III	Free chlorine	2	19,000	18,000	23,000
	Sodium hydroxide and chlorine[c]	2	23,000	14,000	19.000
	....do.[d]	2	22,000	12,000	18.000
	....do.[e]	2	23,000	9,000	10,000
	....do.[f]	2	19,000	7,500	8,000

[a] Electrolytic.
[b] From bleaching powder.
[c] Chlorine added thirty minutes after the hydroxide.
[d] Chlorine added twenty minutes after the hydroxide.
[e] Chlorine added ten minutes after the hydroxide.
[f] Chlorine added with hydroxide.

In series I comparison is made of free gaseous chlorine generated electrolytically, sodium hypochlorite, and potassium hypochlorite. Potassium chlorate and potassium perchlorate are also included, because they are formed in many direct electrolytic processes. The available chlorine of the two latter compounds is taken in an elecrolytic equivalent sense, and would be better expressed by the term 'oxidizing power." Three parts per million of available chlorine vere used in all the tests of series I.

In series II comparison is made of free gaseous chlorine, potassium ypochlorite prepared from bleaching powder, and the same com-ound electrolytically prepared by the recombination of the products f the electrolytic cell. In this and in the next series two parts per nillion of available chlorine were used, because it was found that omparisons are more readily made where the disinfection is not so early complete.

In series III free chlorine was again used and was compared with the electrolytic hypochlorite. In this set of experiments, however, the hypochlorite was made in the sewage by adding separately the chlorine water and the sodium hydroxide. In three sets of tests the addition of the hydroxide preceded that of the chlorine by ten, twenty, and thirty minutes, respectively. The object of this procedure is to determine whether the caustic soda and the gaseous chlorine possess separately better penetrating powers than the hypochlorite does. If such were the case, formation of the hypochlorite within the solid particles of the sewage might result in more complete disinfection than could otherwise be obtained.

The results indicate plainly that hypochlorites are the most efficient germicides. Gaseous chlorine is almost as good, but in each series the free chlorine is somewhat inferior to the hypochlorite. Chlorates and perchlorates have almost no value in disinfection. The formation of these compounds in the electrolytic cell is, therefore, a total waste of energy, and should be prevented as far as possible. Production of these compounds explains in large measure the inefficiency of hypochlorite cells. Hypochlorites made electrolytically are slightly inferior to the market product, but this difference would probably be inappreciable in large-scale tests, where the conditions under which the hypochlorites are prepared are more nearly those of commercial practice. Hypochlorites of different bases evidently have the same value; the results obtained with the sodium and the potassium salts are practically identical and are similar to those obtained in practice with the calcium salt. The claim that the magnesium compound is more efficient than the calcium compound was not investigated. Hypochlorites can be made advantageously by mixing dilute solutions of free chlorine and sodium hydroxide, the products of the electrolytic cell, but the mixing should take place either in the sewage or in cold dilute solution, as otherwise chlorates and perchlorates will be formed; if the hydroxide is added a short time before the chlorine, it is removed from the solution, leaving free chlorine uncombined and leading to a more rapid exhaustion of the available chlorine.

These tests have an interesting bearing on the question of the exhaustion of the chlorine. It appears that the chlorine attacks the organic matter and the bacteria simultaneously, but that its effect on the former is a direct function of its concentration, while its germicidal effect does not bear such exact relation. If these are the true conditions, the successive addition of small portions of chlorine, or what amounts to the same thing, the addition of a substance that yields chlorine slowly, prevents the rapid reduction of the chlorine by the organic matter and prolongs the time of contact with the bacteria. In series III, Table 33, more or less of the hydrate was consumed in saponification before the chlorine was added, the amount so removed depending on the time that elapsed between the addition of the hydroxide and the addition of the chlorine. The first set of series III, therefore, represents the action of free chlorine, and the last set the action of hypochlorite, with the intermediate tests representing different proportions of the two substances. The progressive nature of the final results indicates strongly the necessity of having the chlorine combined in such form that its action on organic matter is retarded. The same effect is shown in the work on crude sewage described on pages 37–51. In the experiments reported in Table 22 decidedly better results were obtained by adding the hypochlorite in four equal portions at hourly intervals than by adding the entire amount at once. In practice the effluent to be treated should never be acid in reaction; it is probable that the addition of lime would still further decrease the rate of decomposition of the hypochlorite and increase its bactericidal efficiency.

EFFECT OF CALCIUM HYPOCHLORITE ON COLON AND TYPHOID BACILLI.

The colon bacillus has been employed in this and in other work as a convenient test organism with which to measure the efficiency of the disinfection process. For obvious reasons experiments on a large scale with the typhoid bacillus are out of the question. Consequently, a comparison was made between the relative resistance of the typhoid and the colon bacilli under controllable conditions, with the idea that in practice the effect of the disinfection process on the former could be measured by its effect on the latter. Emulsions of the two organisms in tap water were treated with hypochlorite solution, and the parallel tests with the two species were made at the same time and were kept as nearly alike as possible. The number of bacteria per cubic centimeter was determined at the end of twenty, forty, and sixty minutes, and two, four, and eighteen hours, and twelve tests of each kind were made in the same manner. The available chlorine ranged from 3.5 to 6 parts per million, averaging 5 parts. The results of the individual tests varied greatly from day to day, because, no doubt, of difference in the character of the growths and in the amounts of organic matter introduced with the organisms. Yet the average figures obtained from these twelve sets of tests probably give a fair basis for estimating the comparative resistance of the two organisms to the disinfectant. The per cent removal has been calculated and the average results are presented in Table 33.

TABLE 33.—*Comparative resistance to calcium hypochlorite of B. typhi and B. coli in aqueous emulsion.*[a]

Tests made at end of—	Removal of bacteria (per cent).	
	B. typhi.	B. coli.
20 minutes	90.5	92.0
40 minutes	98.2	98.0
1 hour	99.45	99.53
2 hours	99.60	99.70
4 hours	99.92	99.96
18 hours	99.99+	99.99+

[a] Average available chlorine, 5.0 parts per million.

The slight differences shown by the experiments on the two organisms may be attributed to experimental variations. The work is not conclusive because other strains of organisms might have yielded different results, but it indicates in a general way that *B. coli* may reasonably be regarded as test organisms in disinfection work and that the process may be expected to destroy typhoid organisms present at least as thoroughly.

It is interesting also to note that the per cent removal of *B. coli* after four hours is about the same as that recorded in the experimental disinfection of crude sewage; namely, 99.96 per cent as compared with 99.93 per cent.

PRACTICAL APPLICATIONS AND COSTS OF DISINFECTION.

The experiments that have been described were sufficiently prolonged and varied in their scope to justify the application of the chloride of lime treatment to practical disinfection on a large scale. It is not possible, however, to draw general conclusions regarding the amount of chlorine necessary for the disinfection of effluents, much less of crude sewage, because the dose is determined largely by the character of the organic and reducing matters contained in the sewage or the effluent. But the investigations have shown what may be accomplished under several conditions and they have established certain probable maximum amounts of chlorine for particular classes of sewage and effluents. They have demonstrated, for example, that trickling-filter effluents similar to those tested may be satisfactorily disinfected with three or four parts per million of available chlorine, and that such quantity will usually be sufficient to effect the removal of 95 per cent or more of the total bacteria in the effluent. If the effluent should contain only 25 per cent of the original sewage bacteria, the whole purification process would result in a removal of 98.8 per cent of the total number of bacteria. The per cent removal of *B. coli* and of typhoid organisms will be at least as high if not higher. Crude Boston sewage can be disinfected to about the same extent with from four to six parts per million of available chlorine. It may reasonably be inferred, therefore, that five parts per million of chlorine represent the maximum concentration that would ever be necessary for the disinfection of a fairly stable effluent, since no such effluent would contain as much oxidizable organic matter as the crude sewage that is treated. The septic sewage of Red Bank probably represents a maximum condition for crude sewage, because its high content of hydrogen sulphide and other oxidizable matters would probably never be exceeded in crude sewage, or at least in sewage from American cities. The disinfection of crude sewage, therefore, would require four to twelve parts per million, of available chlorine, depending on the character of the sewage and its content of oxidizable matters. It will probably be undesirable to treat septic sewage, but if such sewage should be treated, from ten to fifteen parts of chlorine, or perhaps more, would be necessary. The extreme variability of the composition of septic sewage makes it almost impossible to fix a maximum limit for the amount of hypochlorite. The amount of disinfectant required in any plant would necessarily be determined before final adoption of the plan, but these estimates will serve as useful guides, and the limits assigned include the majority of probable conditions.

No data have been obtained with effluents of higher degree of purity than those from trickling filters. The general conclusions from the work have been that the disinfectant action is a function of the chlorine concentration and of the time of contact, and that the time is determined largely by the rate at which the chlorine is consumed by the organic matter. Effluents of a better grade would probably require the same amount of chlorine, if the disinfection were to be accomplished within two hours. In the effluents with which experiments were made, the chlorine was practically consumed in two hours, but in a purer effluent chlorine would probably be left. This indicates that somewhat smaller quantities could be used with longer storage periods. A point is soon reached, however, beyond which the cost of storage is greater than the saving in disinfectant. Effluents of high degree of purity could probably be disinfected with one part of available chlorine, but a contact period of at least five hours would be required for satisfactory removal of the bacteria. One part is robably the minimum amount of chlorine that can be used, as the ecessary time of contact increases very rapidly with decreasing oncentration of chlorine.

One of the most important practical points that has been develped is the relation between organic matter, time of contact, and mount of chlorine necessary. Obviously a definite concentration of hlorine acting for a given time will bring about a definite result ndependent of the nature of the solution. If, however, chlorine is being consumed by the solution itself a greater amount will have to added at first in order to maintain the same average concentration. On the other hand, longer periods of contact with lower chlorine concentration are possible with the better grades of effluent. The experinents with various kinds of sewage make it possible to formulate a crude rule, which may be stated as follows: The product of the initial concentration multiplied by the time in hours required for complete reduction of the available chlorine should be about five for satisfactory disinfection, except that the contact period must not be less than half an hour in any case.

It is possible to fix within narrow limits the cost of chlorine disinfection. The cost is determined chiefly by the concentration of chlorine necessary and the related factor of contact period, and secondarily by the size of the plant. The unit used in the following summary of costs is a plant with a daily flow of 5,000,000 gallons of sewage, such a plant being the smallest that would require the entire time of an attendant, a part of whose salary may legitimately be charged to disinfection. On larger works the labor costs would increase proportionately, and on smaller works arrangements would naturally be made by which the plant could receive proper attention in connection with the regular work of the sewer or street department. The price of bleaching powder has been estimated at $24 a ton delivered at the plant; it is quoted at from $22 to $25, and a price as low as $20 is obtained on large orders by certain paper mills. The price taken is, therefore, sufficiently high to cover the cost of the moderate-sized shipments that would be required for a 5,000,000-gallon plant. A 50,000,000-gallon plant could obtain its bleaching powder for at least 10 per cent less. This bleaching powder would contain over 35 per cent available chlorine, but in order to allow for waste 33 per cent has been taken as the average figure. Labor is computed at $2 for an eight-hour day. Two hours a day—an ample allowance—are reckoned for the care of a 5,000,000-gallon disinfecting plant using 5 parts or less of chlorine. For over 5 parts the time would increase proportionately. Interest, depreciation, and other fixed charges are computed as 6 per cent of the cost of the additional works made necessary by the disinfection treatment; as the construction is chiefly masonry, but little depreciation need be allowed. In certain projects sedimentation tanks would already be available, so that the application of disinfection would not require the construction of storage tanks. For this reason the item storage tanks has been separated from the other fixed charges that include 6 per cent of the cost of mixing tanks and storage tanks for the solution, pumps, piping and connections, and suitable housing. In handling the chemicals for a plant requiring 3 parts per million or more of chlorine, some form of power mixer would be economical, and that item has been estimated. In small plants the mixture of bleaching powder and water would be settled and the solution decanted, but in the larger works the whole mixture would be used, and it would require constant stirring. The increased power item would be more than counterbalanced by the saving in tank construction. Table 34 contains a summary of the cost estimates for chlorine concentrations from 1 to 15 parts per million.

TABLE 34.—*Estimates of the cost of maintenance and operation of a plant for disinfecting sewage or effluent with chloride of lime, based on a capacity of 5,000,000 gallons a day.*

Available chlorine (in parts per million).	Time of contact (in hours).	Cost per million gallons.					
		Storage tanks.	Other fixed charges.	Bleaching powder.	Labor.	Power.	Total.
1	5.0	$0.10	$0.02	$0.30	$0.10	....	$0.52
2	2.5	.05	.04	.60	.10	....	.79
3	1.6	.04	.05	.90	.10	$0.02	1.11
4	1.2	.03	.07	1.20	.10	.02	1.42
5	.8	.03	.08	1.50	.10	.03	1.74
10	.5	.02	.16	3.00	.15	.06	3.39
15	.5	.02	.24	4.50	.20	.09	5.05

The estimates made for a 5,000,000-million gallon unit can be safely applied to larger works, and they are applicable within reasonable limits to small works that are properly managed. The cost of the tanks and of covering them would become proportionately cheaper with increased size, but this saving would be offset by the advisability of better construction and architectural embellishment. The saving due to decreased price of bleaching powder for a 50,000,000-gallon plant, using 3 parts per million of chlorine, would be about $4.50 a day, which would approximately pay for the additional chemical and bacteriological control required by a plant of such size. On very large works labor items would not increase proportionately, because most of the work would be done by machinery.

In an earlier paper[a] the opinion was expressed that the expense might be considerably reduced and efficiency increased by using trolytic chlorine produced at the disposal works instead of ching powder. The relation of electrolytic processes to sewage nfection is still unsettled, but a study of the present possibilities such processes and experimental work with the McDonald cell with small cells of special design have indicated that the margin cost between the alternative methods is so slight that it hardly tifies the additional effort and the uncertainty involved in the ablishment of an electrolytic plant. A brief discussion of recent velopments in this field will show the reasons for this conclusion. o general types of electrolytic process are available, in both of ich the electric current is passed through a solution of sodium loride, chlorine being liberated at one electrode and caustic soda the other. In one type these products are allowed to recombine, rming sodium hypochlorite and certain other compounds. In the her type the products are removed from the cell as quickly as ssible, the aim being to prevent their recombination. Numerous ocesses of the first kind have been developed, of which the Hermite d Woolfe processes have already been mentioned. The commercial preparation, called "Chloros," is made in this way. The ost recent, and probably the most improved, cell of this type has cently been described by Digby and Shenton.[a] The reaction by hich the hypochlorite is produced from chlorine and caustic soda cold dilute solution is:

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[a] Phelps, E. B., and Carpenter, W. T., The sterilization of sewage filter effluents: Tech. Quart., vol. 19, 1906, p. 382; Contr. from Sanitary Research Lab., vol. 4, 1908.

$$(1)\ 2\,NaOH + 2Cl = NaOCl + NaCl + H_2O.$$

In the paper just cited Digby proposes the reaction,

$$(2)\ NaOH + Cl = NaOCl + H.$$

He bases his view on the observation that the electro-chemical fficiency of the cell is over 50 per cent. Aside from the obvious mpossibility that a reaction can produce at one and the same time ascent hydrogen and a strong oxidizing agent, it is apparent that eaction (1), if it were carried out completely, would yield a product ontaining not 50, but 100 per cent of the available chlorine initially present. The conception that this reaction represents a loss of half the available chlorine is due apparently to a mistaken idea of the term available chlorine, which, as has been explained on page 18, is really a misnomer. The fact is that the oxidizing power, or the available chlorine as ordinarily determined, of the products of reaction (1) is equivalent to twice the chlorine of the hypochlorite, or to the total chlorine present. There is, therefore, no apparent basis for the reaction proposed by Digby, which would yield twice as much available chlorine as the amount allowed by the law of electro-chemical equivalents. The reactions of equation (1) are complete only in cold dilute solutions. If the solution is hot or if it is concentrated chlorates and perchlorates are produced simultaneously. It is for this reason that the disinfectant value of these two sets of compounds was determined in an earlier part of the present investigation. It was found that they possess practically no disinfecting power and that their production in the cell represents a loss of energy. Economy in electric current demands strong salt solutions and high current densities with consequent heating of the electrolyte. Electrical efficiency is, therefore, opposed to chemical efficiency, and the problem in designing cells of this type is to balance the two efficiencies in the most economical manner. The electro-chemical equivalent of a current of one ampere is 1.32 grams an hour of chlorine, and this equivalent is not modified by the voltage. However, as the total energy employed in a process determines its cost, it is necessary to consider voltage as well as current in discussing electrolysis. In any electrolytic reaction there is a definite minimum voltage required for carrying out the reaction, and this can be computed from thermal considerations as follows: The complete reaction in the cell before the recombination of the hydroxide and the chlorine may be written,

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[a] Digby, W. P., and Shenton, H. C. H., Surveyor, vol. 30, 1906, p. 653.

$$NaCl + H_2O = NaOH + H + Cl.$$

Substituting the heats of formation of these compounds gives

$$964 + 684 = 1118 + x, \text{ whence}$$

$$x = 530 \text{ calories (K)}.$$

Here x is the heat required by the reaction, expressed in calories (K) per gram-equivalent of the reacting substances, and its value is 530 calories. One gram-equivalent of substance is transformed with the passage of 96,540 coulombs of electricity, and one coulomb transferred under a difference of potential of one volt has an energy equivalent to 0.00241 calories. Therefore, one electro-chemical equivalent of current at a difference of potential of one volt has a heat value of 96,540 multiplied by 0.00241, or 232.7 calories. Consequently the voltage required to effect the desired reaction, which calls for a heat absorption of 530 calories per equivalent, is 530 divided by 232.7, or 2.28 volts. This is the minimum voltage with which the reaction can take place, and efficiency calculations to an energy basis must be referred to this voltage. At a difference of potential of 2.28 volts, one kilowatt gives 439 amperes, so that an output of 579 grams of chlorine per kilowatt-hour represents a process of 100 per cent efficiency on both a current and an energy basis. In practice a current at a tension of at least 4.5 volts is usually found necessary, even with strong solutions of salt and with electrodes placed as near together as possible. This factor alone reduces the energy efficiency to 55 per cent with perfect current efficiency. The current efficiency depends especially on the design of the cell. If there are no complicating secondary reactions during the recombination of the products it approaches 100 per cent very closely, and this is also the case in the most improved design of chlorine cell in which recombination does not take place. It is clear that the production of hypochlorite in one operation within the cell is not economical, and a review of the available information and a laboratory study of various hypochlorite cells have led to the conclusion that cells of that type can not be expected to yield much more than one-half the available chlorine that can be obtained from the same electric current by means of direct chlorine cells.

Direct chlorine cells have been developed to a high degree of efficiency, and this is the type of cell which has been considered in the present studies of sewage disinfection. The McDonald cell, which was used to some extent in this work, is giving in a regular installation in a large paper mill a current efficiency of over 80 per cent at 4.5 volts, making the total energy efficiency over 43 per cent. The most recent development is the Townsend cell, for which current efficiencies exceeding 98 per cent are claimed at a tension of 5 volts or more. The special feature of the Townsend cell is an arrangement by means of which the caustic liquor drops into a bath of oil as soon as it is formed, a step that prevents recombination. In spite of the high efficiency of such cells, it is not practicable to employ them in sewage work on account of the small margin between the market cost of chlorine and the cost of its manufacture electrolytically. This condition is due to the fact that the demand for caustic soda is so much greater than that for chlorine that the chlorine is to a certain extent a by-product and can be made into bleaching powder and sold at low cost. On the other hand, the manufacture of small amounts of caustic liquor at the disposal works does not warrant the installation of the necessary machinery for the production of pure caustic soda; consequently, without a market for this by-product, the cost of the chlorine would be the entire cost of the operation. In addition, a skilled chemical engineer who would be required would increase the cost per million gallons much more in a small plant than in a large one, while the uncertainty of the process and the increased responsibility on the sewage works both offset any slight advantage in cost which might appear in favor of the electrolytic plant. It has also been made clear in the present studies that the use of free chlorine, as contemplated in the earlier plan, is not economical and that some base should be provided for the preparation of hypochlorite. This base might be the caustic soda yielded by the process, or if a market for that by-product were available, lime could be used.

For the reasons outlined, therefore, this investigation of the possibilities of the electrolytic processes indicates that, contrary to earlier views, such processes are not well adapted at the present time to sewage disinfection. Nor does it seem probable that hypochlorite from cells in which the products are allowed to recombine within the cell will ever be able to replace ordinary bleaching powder.

CONCLUSION.

The main reason for disinfecting sewage lies in the probable effect of discharging pathogenic bacteria into lakes, rivers, and harbors. Any such discharge is obnoxious to the sanitarian, and when the practice of computing the cost of typhoid-fever epidemics becomes more general the cost of disinfecting sewage will not appear excessive. At present, however, the demand for sewage disinfection is confined to two conditions, namely, the possible pollution of water supplies and of shellfish beds. It has not yet been decided upon whom the responsibility rests for protecting domestic water supplies. The sanitarian recommends that rivers be kept as clean as possible and that water be filtered, but in practice distinction is made between supplies which are filtered before use and those which are not, and complete disinfection of sewage that enters streams from which supplies of the first kind are derived is still regarded as an unreasonable demand. The concensus of competent opinion requires at least, however, that, if an effluent is discharged within the region of important shellfish beds or into a stream which is used as a source of domestic water supply without filtration, such effluent shall be free from pathogenic germs. Improved standards in sanitation and improved methods of disinfection will both operate to increase these minimum requirements, but in the meantime a thorough knowledge of disinfection methods and experimentation on the improvement and the cheapening of such methods will do much to hasten their general adoption. Slow sand filtration removes bacteria in a satisfactory manner and almost totally eliminates organic matter. Under certain conditions such a result is highly desirable, but the method is comparatively costly, especially in the larger communities, and it is practically out of the question in many sections of the country.

Chemical disinfection offers a means whereby a reasonable bacterial purification may be accomplished without complete purification of the organic matter. It is in no sense a substitute for sewage purification as ordinarily understood, for, though the application of chlorine compounds to an effluent oxidizes the organic matter in it to some extent and thereby increases its stability, such improvement is only incidental. It is not in anyway comparable with the cost of treatment, and it would be unwise to attempt to obtain stability in such manner. Incidentally, however, the advantages of this increased stability are obtained, and it is probable that rapid sewage filters may be worked at somewhat higher rates and with less margin for safe operation where chlorine treatment is employed as a finishing process. Under certain conditions it may be found desirable to effect bacterial removal without organic stability; along the seacoast and possibly along some great rivers of the Middle West the dilution factor is sufficienty high to preclude the danger of physical nuisance. Under other conditions the production of a stable effluent without regard to the amount of organic matter discharged may suffice; under others the removal of suspended matter may be of prime importance. Due consideration should be given in any particular process to the character of the organic matter in the effluent, and further treatment is advisable, not only where the discharge produces, or threatens to produce, an actual physical nuisance, but wherever the self-purifying powers of the stream will be appreciably drawn upon. In other words, stability is demanded in all effluents, unless the dilution is very great, not only in relation to the local discharge, but also in relation to all the sewage or effluent that the body of water in question may receive. This much is demanded from the standpoint of physical pollution alone. If, therefore, bacterial removal is also essential, disinfection is particularly satisfactory as a finishing process, because it can now be conducted at far less cost than the cheapest form of supplementary sand filtration.

Comparison on a cost basis of the methods of chemical disinfection makes it apparent that chlorine in some form is the most efficient agent, though it must be admitted that the possibilities of heat and of certain organic compounds have not received adequate investigation. Calcium hypochlorite, or commercial bleaching powder, is by far the most satisfactory chlorine compound available. It has greater germicidal efficiency than equivalent amounts of free gaseous chlorine, chlorates, or perchlorates. It is equaled in efficiency by potassium and sodium hypochlorites, the products of certain electrolytic cells. The electrolytic production of hypochlorites or of free chlorine is not a satisfactory source of the disinfectant. The cost of such manufacture, on a scale necessarily small even at the larger sewage-disposal works, is at present so little below the cost of bleaching powder that no safe margin is left to cover the additional responsibility and uncertainty that are involved. Improved processes of manufacture may alter conditions somewhat, but the highest possible working efficiency and the cheapest power would not sufficiently reduce the costs to alter these general conclusions.

The application of 3 parts per million of available chlorine in the form of bleaching powder to a trickling-filter effluent similar to those on which experiments were made effects satisfactory disinfection. The removal of bacteria from the effluent averages over 95 per cent, making the removal for the whole purification process 98 to 99 per cent of the number in the crude sewage. The cost of disinfection ranges from $1 to $1.50 per million gallons of sewage, depending chiefly on the size of the plant. Effluents of higher degrees of purity can be disinfected at still lower cost. Five parts per million probably represents the maximum amount of chlorine required for the treatment of trickling-filter effluents of poorer quality. The results obtained with the amounts of disinfectant that are specified do not, of course, amount to complete sterilization, but they may reasonably be called "practical disinfection." Considerable additional cost is required to improve them but slightly.

The disinfection of crude sewage to the same final condition requires the removal of over 98 per cent of its total bacteria. This may be accomplished by the application of from 5 to 10 parts per million of available chlorine, the amount depending on the character of the sewage. Such disinfection costs from $1.50 to $3.50 per million gallons.

The disinfection of septic sewage requires the application of from 10 to 15 parts per million of available chlorine. If no further purification is required than that given by septic action and by disinfection; it is advantageous to reverse the processes by disinfecting the crude sewage before it enters the tank. The resulting development of saprophytes within the tank has no sanitary significance, and it is doubtless of great advantage in the subsequent purification of the organic matter in the stream.

The removal of *B. coli* is usually somewhat more complete than that of the total organisms. Under the conditions of a laboratory experiment, the results of hypochlorite disinfection on typhoid and colon bacilli in tap water were identical. It seems reasonable to assume, therefore, that the viability of the typhoid organism under working conditions in practical sewage disinfection is at least no greater than that of the colon bacillus and no greater than that of the sewage bacteria as a whole. Consequently the disinfection results obtained with total bacteria may, in the case of chlorine disinfection at least, be referred directly to the typhoid bacillus with assurance of reasonable accuracy.

The results obtained in this investigation are so much more favorable than any results that have been reported for similar work that comment on their accuracy and general applicability seems justifiable. The more important portions of the work have been practically duplicated under as diverse conditions as possible and by different workers. There is no apparent reason for believing that the results are not of general applicability. The reactions involved are particularly free from interference on the part of the mineral constituents of normal sewage, a condition which has not been found where copper has been used as the disinfectant. The satisfactory results in the present work are largely due to the fact that many little difficulties inherent in new processes have been overcome by continuous work extending over considerable periods of time, and in particular to the fact that the experiments were made part of permanent laboratory routine and were free from temporary and special characteristics which usually involve discontinuity and interruption. This routine continued week after week without interruption and without undue attention—in fact, just as it would naturally go on in practice. It is believed that the results represent what may be accomplished in practice and that they can be duplicated under working conditions on any scale which may be desirable.

PUTRESCIBILITY AND STABILITY OF SEWAGE EFFLUENTS.[a]

INTRODUCTION.

The development of modern rapid processes of sewage treatment, involving the use of coarse material, has resulted in a somewhat changed conception of the functions of sewage disposal, while the general introduction of contact and trickling filters in the newer and larger works has made it necessary to examine methods of sewage analysis from a new viewpoint. Certain hitherto important features of the analysis have assumed comparatively unimportant rôles, and new determinations have been developed on which the chief reliance is now placed. In the older methods of sewage purification, almost complete removal of organic matter and oxidation of the nitrogen were obtained, and the analytical methods employed in the control of such plants were designed to test their efficiency in accomplishing these ends. Consequently the determination of nitrogen in its different stages of oxidation and of organic matter in general were paramount. These determinations are only of minor importance in the practical control of modern rapid filters, where oxidation of nitrogen is incidental and removal of organic matter is but slight. Suspended solids, available oxygen, and the character of the effluent in reference to its stability now demand first consideration. As the production of a stable effluent is the primary function of such filters, the determination of stability becomes the most important analytical method in filter control. This point has been generally recognized, and incubation or putrescibility tests of one form or another are in general use, often at places where no further analyses are made. It unfortunately happens, however, that there are many different conceptions of what putrescibility really is and many different methods of determining it. Consequently statements of results lose much of their significance and comparisons are difficult or impossible. The present article is a review of the subject for the purpose of establishing the fundamental facts and of harmonizing current opinions. A method of determining stability, which has been in use by the writer for nearly three years, and a numerical method of expressing results, by which quantitative value is given to the test, are also presented.

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[a] Investigation made at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology.

PUTRESCIBILITY.

Putrescibility, as applied to organic matter in general, implies the ability of that matter to undergo offensive putrefactive decomposition. In a strict sense putrefaction is a term applied to nitrogenous matter only, though this is a popular rather than a logical conception. Exactly what constitutes offensive putrefactive decomposition in a sewage effluent is a matter on which opinions differ. Such decomposition is always anaerobic, and it is usually accompanied by the evolution of offensive odors. These two phenomena have, therefore, formed the basis of most putrescibility tests. Some criteria of putrefaction which have been employed are: (1) Development of offensive odors; (2) formation of black sediment; (3) reduction in the amount of dissolved oxygen; (4) loss of all dissolved oxygen; (5) loss of all available oxygen, including that of nitrates and nitrites; and (6) increase in the oxygen-consumed figure. Some of these tests are based on partial reduction of the available oxygen in the effluent; others depend on the complete reduction of the available oxygen and subsequent anaerobic fermentation. The tests most commonly employed belong to the latter group, depending on the production of odor or of hydrogen sulphide, blackening of the liquid, or reduction of organic dyes. The test which depends on an increase in the oxygen-consumed figure during incubation is also in that class, because anaerobic fermentation alone renders organic matter more readily oxidizable.

These two types of test illustrate two distinct points of view which should be clearly differentiated. An effluent may be regarded as being composed of a given mass of organic matter dissolved or suspended in a definite amount of water. The water contains also a definite amount of available oxygen in the form of free dissolved oxygen, nitrites, nitrates, and possibly of other compounds. All the organic matter is oxidizable to some extent, and to that extent it serves as bacterial food. The greater the amount of organic matter and the greater its oxidizability, the greater is the absorption of oxygen from the medium. Consequently a reduction of available oxygen in the effluent during incubation is a measure both of the amount of organic matter present and of its capability of oxidation. As a small amount of readily oxidizable matter has the same effect on the result as a larger amount of more stable matter, a test of this kind indicates whether or not the organic matter consumes oxygen; but it does not show whether or not the supply of available oxygen is sufficient to prevent the establishment of anaerobic conditions. This important question of the balance between the oxygen demanded by the organic matter and the oxygen available in the liquid is taken into consideration by tests of the second kind mentioned, namely, those dependent on the establishment of anaerobic conditions. Such tests do not involve estimation of the amount and the kind of organic matter; indeed, organic matter which does not absorb any oxygen from the liquid under the conditions of an incubation test must be very highly oxidized; and, furthermore, most organic matter derived from sewage is putrescible in itself—that is, if it is stored by itself in the absence of oxygen, it undergoes putrefactive changes. The question at issue is not, however, whether the organic matter itself will putrefy, but whether the effluent as a whole will become so reduced in oxygen that putrefaction will become possible. In other words, it is simply a question of a balance between the available oxygen of the effluent and the oxygen which the organic matter will require during the incubation period. It would seem that the problem might readily be solved by determining this balance, but, unfortunately, it is not a simple matter, because the action involved is bacterial. Many attempts have been made to determine the oxygen balance analytically, but such tests answer only with very good and very bad effluents, for which an inspection of the sample would serve just as well. When there is doubt about the character of the effluent—the condition for which such information is of most value—all such analytical procedures have heretofore failed. It is evidently impossible to imitate with any degree of precision the bacterial activities that are involved. There remains, then, but one satisfactory expedient: To let the reaction proceed by itself and to note the result. But here also there are difficulties, because bacterial reactions of this sort are necessarily slow in reaching equilibrium, and the time required by a nicely balanced effluent is greater than can be allowed in routine work. Some arbitrary period of time, therefore, is usually adopted, and it is in respect to this factor that the confusion rises. If stability is to be considered a definite qualitative characteristic of an effluent, that characteristic should be determined by a test sufficiently prolonged to insure equilibrium, but such procedure is not feasible for obvious practical reasons, and it is not desirable, because it is not enough simply to know that the available oxygen is sufficient or insufficient to satisfy the demands of the bacteria that are working on the organic matter. If the available oxygen is sufficient, there is perfect stability—a definite condition; if it is insufficient, there is still stability in the quantitative sense—a relative stability determined by the relation of the available oxygen to the total amount of oxygen required by the organic matter for perfect stability. In practice the latter condition is the one usually encountered.

RELATIVE STABILITY.

DEFINITIONS.

The term putrescibility has had so many and so varied meanings in dictionaries, in popular parlance, and particularly in the minds of water chemists, that it is proposed to employ the word *stability* for that desirable quality which is the usual object of sewage purification—the transformation of the organic matter to such form that it is incapable of undergoing offensive putrefaction. This term has the added advantage of implying a positive characteristic that is acquired during purification, and it conveys a much more definite impression of the thing under discussion than the negative term *putrescibility*. A few more definitions are necessary in order to simplify the discussion. The time required to establish anaerobic conditions in an effluent which, on incubation in a closed bottle, is subject to bacterial activities producing such conditions may be called for brevity the *reducing time;* the total amount of oxygen initially present in the form of free dissolved oxygen, nitrites, nitrates, and possibly other combinations may be called *available oxygen;* the term oxygen required for equilibrium or simply *required oxygen* may be understood to express the total amount of oxygen which would be consumed by bacterial action in the effluent if the latter were supplied with an unlimited amount of oxygen and if the reaction were allowed to proceed to a condition of substantial equilibrium. An effluent of the character under discussion is not stable in the absolute sense, because its available oxygen is less than the oxygen required for equilibrium; but, of two such effluents, that one is obviously the better which contains the greater amount of available oxygen in proportion to its required oxygen. In other words, effluents of this class have a certain relative stability which is indicated by the ratio of the available oxygen to the required oxygen. This relative stability, as will be shown, can be measured by the time required to reach the anaërobic stage. The term *stability* without qualification is employed in this paper to describe that condition in which the available oxygen exceeds the required oxygen, and the term *relative stability* is used to indicate the character of the effluent in the sense suggested. A perfectly stable effluent, therefore, has a relative stability of 100 per cent.

It is apparent that time is an important element in stability tests, and that it is not compatible with the idea of relative stability to select an arbitrary period of time for establishing the line of demarcation between stability and putrescibility. It is obviously unfair to record one effluent as nonstable because it "holds up," or fails to putrefy, for only three days and to record another as stable because it "holds up" for four days. A filter might deliver during one week an effluent that would fail to pass a four-day incubation test by a narrow margin and might deliver during the next week almost crude sewage for four days and a passable effluent for three. Obviously, the first week's run would be the better and should be so recorded; but, under the present practice in many places, all the samples during the first week would be putrescible and 40 per cent of those during the second week would be nonputrescible. The first requisite, therefore, in logical study of the problem is that the time required for an effluent to reach a condition of anaerobic decomposition shall be taken as an index of its relative stability. This time element is absolutely indispensable, and any test that is adopted for the determination of relative stability should be of such a character that the length of time required for the sample to reach a given anaërobic condition may be recorded.

ESTIMATION OF THE REDUCING TIME.

Many tests have been devised to determine whether or not an effluent is putrescible, and a review of the subject with the details of the methods proposed has been given elsewhere.[a] In any determination of the time required to exhaust the available oxygen in an effluent the following conditions must be fulfilled: (*a*) The sample must completely fill the bottle, the stopper of which must be tight and must not be removed during the test; (*b*) determinations must be made at a standard temperature; (*c*) observations must be made at least as frequently as once a day. If a test is employed which necessitates opening the bottle in order to observe the condition of the sample, one bottle must be incubated for each day that the effluent is under observation. This is true for any test which depends on a chemical determination of any constituent or which depends merely on the odor developed. Obviously such tests are not well adapted to the conditions heretofore stated. A simpler procedure is one in which the anaerobic condition can be detected by the appearance of the effluent without opening the bottle. The anaerobic fermentation that occurs immediately after the complete exhaustion of the oxygen is usually accompanied by a production of hydrogen sulphide. Consequently an indicator that is sensitive to hydrogen sulphide is advantageous in detecting the beginning of the anaërobic fermentation. Fortunately delicate indicators are available for this purpose, for certain organic dyes are readily reduced to corresponding leuco-compounds under anaerobic conditions. Methylene blue is an organic dye of this character, and it is reduced to its colorless leuco base by hydrogen sulphide, alkaline sulphides, and by the commercial reducers used in dyeing. Its employment for the study of stream pollution was first proposed by Spitta,[a] and it was later more thoroughly investigated by Spitta and Weldert[b] as a test for sewage effluents.

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[a] Phelps, E. B., and Winslow, C.-E. A., On the use of methylene blue in testing sewage effluents: Jour. Infectious Diseases, Suppl. No. 3, 1907, p. 1.

Methylene blue, or tetra-methyl-thionin chloride, is a commercial dye of complex constitution, having the empirical composition $C_{16}H_{18}N_5SCl$. Merck's medicinal preparation is pure and it is preferable to the commercial article for sewage work. It is an extremely sensitive indicator for hydrogen sulphide and other reducing bodies, being decolorized at once in the presence of even small traces; its decolorization by bacterial action has been studied by many observers, the principal of whom are cited by Spitta and Weldert.[c] The technique of its use in testing a sewage effluent is extremely simple. One cubic centimeter of a one-tenth per cent aqueous solution of the dye is added to the effluent in a glass-stoppered bottle of 250 cubic centimeters capacity, and the sample is then incubated either at 20° C. or at 37° C. The blue color of the solution remains practically unchanged till the available oxygen contained in it has been consumed and putrefactive conditions have been established. At this stage the dye is reduced and decolorized. The time required for such decolorization is, therefore, approximately the time required for the exhaustion of the available oxygen. The dye is an indicator for what may be called the oxygen neutral point, the point at which the available oxygen becomes exhausted and anaerobic conditions are established. Some studies[d] made at the sewage experiment station confirm the earlier conclusion of Spitta and Weldert, that the end point indicated by this dye is almost exactly the desired neutral point. The order in which different forms of oxygen are reduced appears to be: Dissolved oxygen, nitrates, nitrites, sulphates, and phosphates. Methylene blue was found to change color practically at the same time as the nitrites in this series. It is readily conceivable that an indicator might possess such properties that it would be reduced before the nitrates or even before the total exhaustion of the free oxygen. Another indicator might change only after the reduction of the sulphates. The fact of this varying end point has been well shown in a recent paper by Clark and Adams.[e] Comparative incubation tests were made with 17 dyes as indicators, only 6 of which were reduced during the incubation. Arranged in the order of their reducibility these are: Indigo carmine (sulphonated indigo), methylene green, and methylene blue; and then, order not stated, congo red, methyl orange, and tropæolin. The average time computed from 26 tests for the reduction of indigo carmine was 2 days; for methylene green the average time was 2.4 days; and for methylene blue, 3.9 days. As it is of course impossible to hasten or to retard the reactions that are taking place, these differences show differences in the end point recorded by the several indicators.

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[a] Archiv. für Hyg., 1903, vol. 46, p. 113.

[b] Spitta and Weldert, Mitteilungen aus der Königlichen Prufungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 6, 1906, p. 161.

[c] Loc. cit.

[d] Phelps, E. B., and Winslow, C-E. A., On the use of methylene blue in testing sewage effluents: Jour. Infectious Diseases, Suppl. No. 3, 1907, pp. 1-13.

[e] Clark, H. W., and Adams, G. O., Studies in incubation tests: Jour. Am. Chem. Soc., vol. 30, 1908, p. 1037.

In the writer's experiments it was shown that the end point indicated by methylene blue is probably that point at which the free oxygen and the nitrates are practically exhausted and reduction of the sulphates is just beginning. This is understood to be the point at which anaerobic conditions are established. The work was not undertaken, however, for the purpose of determining the end point accurately, and it is possible that the end point of methylene blue is a little too far along and that either methylene green or indigotin indicates the desired point more closely. Just as it is essential in other branches of analysis to specify the indicator that shall be used in a given determination, in order to prevent confusion in comparative work, similarly it is important in this test to adopt a standard indicator as a basis of comparison. The results of all experiments thus far are in favor of methylene blue, and that dye is now widely and satisfactorily used in the laboratories of the country; consequently, its retention as a standard appears advisable, at least until further experimental evidence is available. The present series of comparative stability values is calculated on the assumption that methylene blue be used. A change in the final end point adopted would, of course, necessitate a remodeling of the computations.

THEORETICAL RELATION BETWEEN REDUCING TIME AND RELATIVE STABILITY.

The time required for complete exhaustion of the oxygen from an effluent—the reducing time—is obviously not a simple function of its relative stability; but there is a well-known theoretical relation between velocity of reaction and amount of reacting substance, from which it is possible to compute one from the other. It is a principle of physical chemistry that the velocity of a chemical reaction is a function of some power of the concentrations of the reacting substances. In the simplest cases the velocity varies directly as the concentration. The bacterial reactions that have been investigated also conform to this law,[a] and it has been, therefore, applied to he present study. The exact expression of the function need not e detailed, for it can easily be seen that this general law is approxinately applicable; if one-half the work of oxidation is accomplished n one day, the availability of the organic matter as a food supply s reduced one-half, and the consequent bacterial activity on the rganic matter is reduced accordingly; at the beginning of the econd day food supply and bacterial activity are in the same relaive proportions and the same relative amount of work is done again; hat is, one-half of the remaining work of oxidation will be done uring the second day. This law is expressed by the following quation:

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[a] Chick, H., An investigation of the laws of disinfection: Jour. Hyg., vol. 8, 1908, p. 92.

Lubenau, C., Zur Saürebildung der Diphtheriebazillen: Arch. f. Hyg., vol. 66, 1908, p. 305.

Famalener, W., and Madsen, T., Die Abschwächung der Antigen durch Erwärmung: Bichem. Zeitung, vol 11, 1908, p. 186.

Nawiasky, P., Uber die Umsetzung von Aminosaüren durch *B. proteus vulgaris:* Arch. f. Hyg., vol. 66, 1908, p. 209.

$$\log. x = \log. a - k^t$$

in which a is the amount of oxygen required for equilibrium at the commencement of the action, and x is the amount similarly required at the end of the time t, while k is a constant known as the velocity constant. If a grams of oxygen are required for initial equilibrium, and if x grams are required after the sample has been incubated in a tight bottle for a period of time which may be termed t days, $(a-x)$ grams of oxygen have been abstracted from the liquid by the organic matter. If the available oxygen of the liquid has just become completely exhausted at the end of t days, the value $(a-x)$ represents the amount of available oxygen originally present in the sample. It is not even necessary to know the actual amounts of oxygen, because the ratio of available oxygen to the oxygen initially required for equilibrium gives a relative stability factor that obviates the expression of the actual amounts. The ratio is

$$\frac{a-x}{a}$$

The value of this expression in terms of t and k can be found by using the logarithmic equation given above:

$$\frac{a-x}{a} = 1 - k^t$$

The second term of this equation, therefore, is equal to the ratio between the total available oxygen and the oxygen required for equilibrium, the ratio being expressed in terms of a constant and the reducing time. This ratio is the relative stability.

If a and x could be determined by analysis it would be possible to determine the value of k by a few tests. It has already been shown, however, that there is no simple chemical method of determining the amount of oxygen which is consumed by the organic matter under natural conditions. A possible method involves actual measurement of the amount of oxygen absorbed by the liquid in a time sufficiently prolonged to insure virtual equilibrium. If, however, k is determined only approximately and if a series of values for $(1-k^t)$ is obtained for all values of t, the terms of this series bear practically a constant relation to each other, even if k is varied considerably. The number expressing the relative stability is, in any case, a true index of the character of the effluent, independently of the further requirement that it shall be the absolute ratio of the available oxygen to the required oxygen. If it is not this absolute ratio it stands in constant but unknown relation to it.

An indirect method has been devised for determining the value of k with a degree of accuracy which is ample for the present discussion. For this purpose the results of 2,649 separate stability tests have been analyzed. The nature of these samples and the manner of determining the reducing time t is described on pages 78 to 80. It is sufficient to state that the reducing time was from one to twenty days in most of the tests, while many of the samples showed a relative stability of more than 100 per cent. As the samples which required a reducing time between one and twenty days had relative stabilities ranging from zero to 100 per cent, it was assumed for the purpose of approximating the value of k that one-half had values less than 50 per cent and one-half values greater than 50 per cent. Such assumption, of course, is justifiable only with a large number of observations, but it is believed that it is sufficiently accurate in the present case. Inspection of the tabulated results showed that a stability of 50 per cent was attained, at a temperature of 20° C., in almost exactly three days, thus making

$$1-k^3=0.50; \text{ or } k=0.794.$$

If this value of k is substituted in the equation before mentioned, the following values of the relative stability corresponding to the time t in days are obtained.

TABLE 1.—*Relation between reducing time and relative stability at 20° C.*

Reducing time in days. (t.)	Relative stability. ($1-0.794^t$.)	Reducing time in days. (t.)	Relative stability. ($1-0.794^t$.)
1	21	9	87
2	37	10	90
3	50	11	92
4	60	12	94
5	68	14	96
6	75	16	97
7	80	18	98
8	84	20	99

These values of relative stability are strict measures of the character of the effluent. An effluent which contains more than sufficient oxygen to establish stability should have a stability of 100; in other words, it would never reach the anaerobic stage. In practice it is necessary to set some time limit to the tests and give an average tability value to all tests exceeding this limit. This value is sufiiciently high to indicate the character of the effluent. On the ther hand, crude sewage containing a little dissolved oxygen is ompletely reduced in one or two hours, or, if it contains no dissolved xygen, decolorizes methylene blue at once; in numerical expresion its relative stability is practically zero. These figures are comarative, because they may be added and divided to obtain periodical verages and the averages thus obtained are properly weighted. This is not so if the reducing times themselves are averaged. The igures are also an approximate measure of the ratio between the otal available oxygen in the effluent and the amount of oxygen equired for the production of stable equilibrium in the organic matter, and it is believed that the approximation is sufficiently close for ordinary purposes of interpretation.

DETERMINATION OF RELATIVE STABILITY.

INCUBATION PERIODS.

Relative stability as previously defined is a numerical measure of the relation between available oxygen and required oxygen and it is also a function of the reducing time. Some practical applications of the stability values in Table 1 remain to be outlined.

Incubation periods exceeding five days are inconvenient and probably unnecessary in practical work, but in experimental work where more detailed knowledge is desired, longer periods may be used to advantage. At the sewage experiment station, a fourteen-day period has been adopted. During the past two years tests have been made of more than 2,600 samples of trickling-filter effluents of such a quality that most of them were near the border line between satisfactory and unsatisfactory effluents. Most of them were on the safe side, but some of them were unsatisfactory for considerable periods. The results of this large number of tests, therefore, constitute an admirable basis for studying the advisability of using shorter periods of incubation. In the summary of the results in Table 2 the tests are divided first in ten groups corresponding to the different filters and the years during which the tests were made. Effluents A, B, C, and D are from trickling filters before sedimentation; E and F are the same effluents after two-hour sedimentation. The results in each group are subdivided in order to show the per cent of the number of samples that retained available oxygen at the end of stated periods. The results shown in this table have been platted and from the plats the number of samples which would have retained available oxygen after twenty days have been determined by exterpolation from a plat of the results for shorter periods of time.

TABLE 2.—*Summary of stability tests of trickling-filter effluents, showing time required to exhaust the available oxygen.*[a]

Effluent.	Period.	Number of samples tested.	Per cent of samples retaining oxygen after—									
			1 day.	2 days.	3 days.	4 days.	6 days.	8 days.	10 days.	12 days.	14 days.	20[b] days.
A	1906-7	388	91	83	75	67	58	54	48	45	42	35
B		388	93	87	81	76	67	62	58	56	53	45
C		388	97	91	86	83	78	74	72	70	70	69
F		388	97	93	91	88	84	81	77	74	73	71
A	1907-8	223	38	32	28	25	22	20	17	15	15	14
B		225	39	31	25	22	14	9	6	5	4	3
C		212	29	19	12	6	5	4	3	3	2	1
D		189	17	5	1	1	0	0	0	0	0	0
E		38	50	37	21	11	5	5	2	0	0	0
F		210	20	14	10	6	3	2	1	1	1	1

[a] Indicator, methylene blue; temperature of incubation, 20° C.

[b] Values exterpolated.

If it is assumed that in practice an incubation period of four days at 20° C. will be employed, it is possible to show from the data in Table 2 what relative stability values should be assigned to samples that retain some available oxygen after four days. Such samples may be divided into two hypothetical groups, namely, those which would have lost their oxygen between four and twenty days and those which would have retained it more than twenty days. Obviously a relative stability of 100 may be assigned to the latter because the value at twenty days is 99. An average time of ten days may be selected for the period between four and twenty days, thus making proper allowance for the decreasing number of samples, which reduce each day, and a relative stability of 90 may be assigned to that group. Between 43 and 63 per cent of the samples which passed the four-day period were reduced before twenty days. This per cent varied with the quality of the effluent, but it may be taken as 50 per cent without introducing an error of more than 5 per cent in the final result in any group. For practical purposes it may be assumed that one-half of all tests passing a four-day period of incubation will be reduced before twenty days, or in an average time of ten days, and that one-half will exceed twenty days. This gives 95 for an average relative stability value of the whole number of samples. If a four-day period of incubation at 20° C. is adopted, each sample reduced on the first, second, third, or fourth day may be recorded as having a relative stability of 20, 37, 50, and 60, respectively, and all samples retaining available oxygen after four days may be given a relative stability of 95. An individual result obtained in this manner will have but little accuracy, and when only a few tests are made, an incubation period of at least 10 days should be employed. On the other hand, when daily tests are made, the method outlined will give for monthly periods average results that are very close to the truth. Relative stability values calculated from the data in

Table 2 for the entire twenty-day period of incubation are compared in Table 3 with similar values obtained by the shorter, four-day, method. The agreement is satisfactory. If smaller numbers of tests are considered, the distribution naturally will not be so regular and greater errors will be introduced in the results calculated. In order to determine the accuracy of the proposed method, the first 776 samples of Table 2 have been subdivided into twelve quarterly groups, containing from 36 to 78 samples in each group, and the relative stability values have been calculated for these smaller groups, as shown in Table 4.

TABLE 3.—*Comparison of relative stability results obtained from the twenty-day incubation period shown in Table 2 with those calculated from a four-day period.*

Effluent.	Period.	Relative stability.	
		20-day period.	4-day period.
A	1906–7	76	77
B		81	82
E		88	86
F		86	84
A	1907–8	43	43
B		39	41
C		31	31
D		25	25
E		38	39
F		28	28

TABLE 4.—*Comparison of relative stability results obtained from smaller numbers of samples by the use of four, six, and twenty day incubation periods.*

Effluent.	Quarter.	Number of samples averaged.	Relative stability based on a—		
			4-day period.	6-day period.	20-day period.
A	1906.				
	First	37	59	59	58
	Second	73	57	53	52
	Third	59	64	61	60
	Fourth	77	89	88	88
	1907.				
	First	74	92	92	92
	Second	68	91	91	92
B	1906.				
	First	36	62	61	59
	Second	71	75	69	69
	Third	59	81	79	82
	Fourth	78	86	84	90
	1907.				
	First	75	91	90	95
	Second	69	91	90	93

The maximum error with the smaller groups is about 10 per cent, and this error can be materially reduced by basing the calculation on a somewhat longer incubation period. The second column in Table 4 shows the relative stability values calculated from a six-day period, and the maximum error in this computation is less than 5 per cent. If the greater number of the samples of a well-purified effluent retain oxygen after four days, the results with any short method of calculation will be low. Since a value of over 95 can not be obtained with this method, it is obviously impossible to provide a four or six day method which will give accurate results. If more accurate information is necessary, longer periods of incubation—perhaps as long as ten days—are advisable. It matters little, however, whether the relative stability is 95 or 99, as far as practical results are concerned, because either value represents a high degree of purification.

EFFECT OF TEMPERATURE ON THE REDUCING TIME.

It has been assumed in the foregoing discussion that the temperature of incubation is 20° C., and there are certain reasons why this temperature is better than higher ones. It probably represents more nearly than any other the average temperature of streams, and results depending on bacterial activity should be obtained near the normal temperature to which the bacteria are exposed in nature. Incubations at 37° C., for example, probably cause the development of a class of bacteria quite different from those normally at work. The most serious objection to higher temperatures, however, is the fact that certain effluents, particularly those from the rapid filters which are in such common use, contain a large amount of dissolved oxygen, frequently 8 or 10 parts per million, and this represents the greater part of the available oxygen. At 20° C. 9 parts per million of oxygen is the saturation point. The saturation point at 37° C. has not been determined, but it is not over 7 parts per million, so that there is a tendency for some of the dissolved oxygen to escape at high temperatures. Tight stoppers will not prevent the escape of this released gas unless great care is taken with them, and mercury seals are hardly adapted to routine work. It is therefore practically impossible properly to maintain the necessary saturation conditions at a temperature higher than 20° C. A variation of temperature with season would have certain advantages, but such adjustment is rather impracticable. Since results are frequently obtained at 37° C., the relation of such results to those obtained at 20° C. has been investigated and has already been reported.[a] Variable relations were found, as was expected, but the average results may be used with some degree of accuracy. It was found that the time of reduction at 37° C. was from 37 per cent to 72 per cent of that required at 20° C., and the mean of 20 determinations was exactly 50 per cent. Carefully fitted glass stoppers were used in the bottles, and ordinary precaution was taken to prevent loss of oxygen. If haste is necessary, a temperature of 37° C. will give results in about one-half the time required at 20° C. But the use of a temperature of 20° is strongly recommended whenever it is possible to employ it.

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[a] Phelps, E. B., and Winslow, C. E.-A., loc. cit.

SUMMARY OF METHOD.

Samples should be collected in glass-stoppered bottles of 150 or 200 cubic centimeters capacity. No special precautions are necessary in collecting samples of ordinarily good effluents that are fairly high in dissolved oxygen. If the dissolved oxygen is low, precautions similar to those used in collecting dissolved oxygen samples should be observed. A one-tenth per cent solution of methylene blue, preferably Merck's medicinal quality, is used as indicator. One cubic centimeter of this solution is added to each of the samples, which are then incubated, preferably at 20° C., for four days, and observations are made at least once a day. The samples in which the methylene blue becomes decolorized are recorded as having a relative stability corresponding to the time required for reduction. Those that are blue at the end of four days are given a relative stability value of 95.

Table 5 gives the relation between time for reduction and the relative stability. Though the figures up to four days are the only ones required, the entire series up to twenty days is given for comparison. Relative figures for incubation at 37° C. also are given, but the use of that column is not recommended, except when it is absolutely necessary to use the higher temperature, or when it is desired to convert results to a standard basis of 20° C.

TABLE 5.—*Relation between relative stability and reducing time at 20° and at 37° C.*

Relative stability numbers.[a]			Relative stabilty numbers.[a]		
t_{20}.	t_{37}.	s.	t_{20}.	t_{37}.	s.
0.5	....	11	8.0	4.0	84
1.0	0.5	21	9.0	4.5	87
1.5	....	30	10.0	5.0	90
2.0	1.0	37	11.0	5.5	92
2.5	....	44	12.0	6.0	94
3.0	1.5	50	13.0	6.5	95
4.0	2.0	60	14.0	7.0	96
5.0	2.5	68	16.0	8.0	97
6.0	3.0	75	18.0	9.0	98
7.0	3.5	80	20	10	99

[a] s=Relative stability or ratio of available oxygen to oxygen required for equilibrium. Expressed in per cent.

t_{20}=Time in days to decolorize methylene blue at 20° C.

t_{37}=Time to decolorize at 37° C.

Theoretical relation—

$s=100\ (1-0.794^{t_{20}})$

$=100\ (1-0.630^{t_{37}})$

INTERPRETATION OF RESULTS.

The arbitrary tests for putrescibility now employed require no interpretation. An effluent is either putrescible or nonputrescible, according to whether it is on one side or the other of a certain line of demarcation. The fact that the dividing lines, for there are many of them, are perfectly arbitrary and have no real significance seems to have been overlooked. Fixed arbitrary standards in sewage analysis are undesirable in that they relieve the analyst of the important and difficult duty of interpreting his own results in the light of his own peculiar environment. Some general observations and rules may be stated for aid in interpretation, but it should always be borne in mind that such interpretations are dependent as much on outside conditions as on the analyses themselves. The mere statement, therefore, that 75 per cent of the samples of a tested effluent were nonputrescible has no bearing whatever on the broader phases of interpretation. These facts are well known and accepted in ordinary analytical features. The aim of the present investigation has been to place the important determination of stability on the same basis. Under this proposed method of determining relative stability an interpretation of the information in hand is rendered possible. A relative stability of 75 per cent means that the effluent in question contains a supply of available oxygen equal to 75 per cent of the amount of oxygen which the effluent will eventually require before it will have become perfectly stable. The amount of this available oxygen is estimated fairly well by the chemical determination of dissolved oxygen and nitrates. The nitrites are usually so low that they are negligible, and it is unnecessary to decide whether or not the nitrates represent available oxygen, because they have been included in the test and must be considered in the interpretation. Undoubtedly the nitrates will not be used in the stream until the dissolved oxygen of the water has been reduced to a low point. Nevertheless, the fact remains that the available oxygen in the effluent, including the nitrates, is 75 per cent of that required for equilibrium, and that the remainder must come from the water of the stream, which must also supply enough additional oxygen to replace that which may be abstracted from the nitrates of the effluent, if aerobic conditions are to be maintained. Analyses of water from the stream and estimates of the relative volumes of the stream and the effluent complete the data necessary for a full interpretation.

In general, effluents having a relative stability greater than 90 per cent may be discharged into any stream without danger of their consuming any of the oxygen of the water, because effluents of such high stability will retain oxygen indefinitely on exposure to the air.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 226

THE POLLUTION OF STREAMS BY SULPHITE PULP WASTE

A STUDY OF POSSIBLE REMEDIES

BY
EARLE BERNARD PHELPS

Investigation made at the Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology

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THE POLLUTION OF STREAMS BY SULPHITE PULP WASTE—A STUDY OF POSSIBLE REMEDIES.[a]

By EARLE BERNARD PHELPS.

INTRODUCTION.

The pollution of streams by the waste liquors resulting from the manufacture of paper pulp by the sulphite process constitutes one of the most serious stream-pollution problems with which science has to deal at the present time. The seriousness of the problem is the direct result of two factors—the tremendous volume of such waste liquors and their high content of organic matter of extremely undesirable character. An approximate estimate of the amount of sulphite waste liquor discharged into the streams of the United States in one year is given in the subjoined statement, compiled from data in Forest Circular No. 120, Forest Service, United States Department of Agriculture.

Amount of sulphite waste liquor discharged into streams of the United States during 1906.

	Million gallons.
Maine	560
Massachusetts	45
Michigan	175
New Hampshire	380
New York	1,000
Ohio	41
Oregon	52
Pennsylvania	217
Virginia	84
West Virginia	89
Wisconsin	540
All other States	44
	3,227

According to the above estimate, the total amount of this liquor discharged into streams throughout the country in one year is more than three billion gallons, and when it is considered that of this enormous amount 10 per cent by weight, or more than 2.5 billion pounds, is solid matter, mostly organic, it will be readily conceded that the problem of its disposal is one of no small magnitude.

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[a] This investigation was made in cooperation with the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology.

STREAM POLLUTION BY SULPHITE PULP WASTE LIQUOR.

GENERAL DISCUSSION.

Though the pollution of streams by sulphite pulp waste is an obvious and serious matter in the region where sulphite mills exist, the literature contains but few references which throw any light on the actual damage caused. In Germany the regulations of the sanitary authorities are strict. Ahrens[a] states that pulp manufacturers, in spite of constant endeavor, may come into conflict with the authorities because they are not able to meet the requirements in regard to the discharge of waste waters into rivers, and he adds that many factories in Germany have actually been obliged to shut down for that reason. Sanitary officers in the United States are more lenient. This is due partly to the fact that the streams in this country are larger and the greater number of the sulphite mills are located in less densely populated regions.

POLLUTION OF LAKE CHAMPLAIN.

In some places stream pollution from this cause has been so serious as to warrant investigation. Leighton,[b] in his investigation of the pollution of Lake Champlain, made a study of sulphite pulp waste as it affects Ausable River, which he found to be a black, foul, grossly polluted stream in which the existence of fish or other forms of life is impossible. He concluded, however, that the great dilution of the river waters by those of the lake renders the pollution insignificant so far as the lake waters are concerned.

POLLUTION OF JAMES RIVER.

Levy[c] made a careful study of the effect of sulphite waste pollution on James River. The sources of pollution are at Covington, Va., about 250 miles by water above Richmond, whose public supply is derived from this stream. Levy found Jackson River, into which this liquor is discharged and which unites with the Cowpasture below Iron Gate to form the James, to be perfectly clear and colorless. The waste entering the stream first turns the water dark brown and later a purplish black. Foam is created at the outfall and wherever the stream is interrupted by falls or by rapids. This appearance can be noted for the entire distance from Covington to Richmond. Dilution is practically the only means of improvement. On the sanitary side of the question Levy considers two problems—(1) whether the substances introduced are themselves actually injurious to health, and (2) what influences they may have on the multiplication of bacteria. The liquor itself as it enters the river is absolutely sterile, not only on account of the actual germicidal substances which it contains, but also on account of the fact that it has been subjected for about twelve hours to steam under a pressure of 80 pounds to the square inch. Its germicidal properties are shown in the following table:

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[a] Zeitschr. angew. Chemie, 1895, p. 41.

[b] Leighton, M. O., Preliminary report on the pollution of Lake Champlain: Water-Supply Paper U. S. Geol. Survey No. 121, 1905.

[c] Levy, E. C., Report to the water committee on the investigation of the effect of trades wastes on the water of James River at Richmond. Richmond, 1905.

Germicidal action of sulphite waste liquor on bacteria in highly polluted water from Shockoe Creek.

[By E. C. Levy.]

Per cent, by volume, of liquor in mixture.	Number of bacteria per cubic centimeter.			Per cent of reduction (−) or increase (+).	
	At start.	After 6 hours.	After 24 hours.	In 6 hours.	In 24 hours.
0 (control)	450,000	900,000	2,500,000	+100	+ 455
1	445,000	....	[a] 7,500,000	....	+1,585
5	427,500	60,000	170,000	− 86	− 60.2
10	405,000	35,000	0	− 91.4	− 100
25	337,500	10	0	−100	− 100

[a] Plate liquefied.

The number of bacteria in the water at the commencement of the experiment is calculated from the number of bacteria present in the creek water itself (450,000). Where the reduction is more than 99.95 per cent it is given as 100 per cent. Even very small amounts of the waste liquor have an antiseptic action, but are not actually germicidal; they restrain the growth of bacteria without killing them. Such action may be harmful rather than otherwise, for in a stream receiving sewage certain kinds of bacteria eventually render the sewage harmless. It would seem that as the character of this waste is so stable it does not furnish food for bacterial growth.

Complaint is made that the water of the James at Richmond is unfit for boiler use, both on account of its corrosive action and on account of the "priming" due to vegetable matter present. Aside from the matter of actual harm, however, Levy states that the water is rendered objectionable in appearance by this waste. The dark-brown, almost black water, with its accumulation of dirty scum, is not relished by the consumer, even if he knows that it is probably safe to drink it. In a bath tub this color is very pronounced, and even in so small a quantity as a tumblerful it is decidedly noticeable. James River is practically clear for certain periods of each year, and at such periods, under normal conditions, no further treatment than mere storage would be required for furnishing satisfactory water. But during these periods, on account of the low stage of the river, the trouble from Covington is most marked. Plain sedimentation has absolutely no effect on the color; but coagulation will remove a large part of it, and Levy found not less than 3 grains of alum per gallon necessary for this purpose. He estimates that with a daily consumption of 14,000,000 gallons it would cost $75 a day for alum, which would not be required if it were not for the sulphite pollution, and states that even then the water would not be perfectly satisfactory.

Farther up the river complaints have been made that fish have been killed by the sulphite waste. The opinion is expressed that if fish are killed it is perhaps because the free oxygen, which is necessary for their life, is used up, rather than because of the presence of substances actually poisonous in themselves.

POLLUTION OF POTOMAC RIVER.

Some experiments to determine the effect of sulphite waste pollution on fish life in Potomac River are reported by Marsh.[a] He found a decidedly injurious effect on fish of different kinds in dilutions varying in strength from 1 part of waste liquor in 50 parts of water to 1 part in 200 parts of water.

POLLUTION OF BLACK RIVER.

Whipple[b] has referred to the effect of sulphite pollution on the water supply of Watertown. He states that the sulphite liquors contribute to the odor and color of the water, and necessitate the use of greater amounts of alum than would otherwise be necessary.

MANUFACTURE OF SULPHITE PULP.

In order that the character and amount of the waste liquors resulting from the manufacture of wood pulp by the sulphite process may be comprehended it will be necessary to describe, in some detail, the various operations that are conducted in a sulphite mill to convert spruce logs into paper pulp. The processes in use at the Mechanicsville mill of the West Virginia Pulp and Paper Company will be described, as they are typical of a modern sulphite mill of average capacity. Though there are naturally many variations in minor details, the essential steps are similar at all mills, so that a detailed description of the processes of one mill, with an occasional statement of important alternative methods, will serve the purpose of this discussion.

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[a] Marsh, M. C., in Parker, H. N., and others, The Potomac River basin: Water-Supply Paper U. S. Geol. Survey No. 192, 1907.

[b] Whipple, G. C., Proc. Watertown Soc. Eng., Watertown, N. Y., 1906.

THE WOOD.

Spruce and hemlock are the woods used almost exclusively for the manufacture of pulp by the sulphite process. The logs are either barked by hand in the woods before seasoning or by machinery at the mill. Machine barking necessitates cutting the log into 2-foot lengths; in hand work 4-foot lengths are used without further cutting. Machine barking also causes some waste of material through cutting too deeply into the log. Some measurements of logs barked by machinery show that the original circular section of the log had been changed to that of a circle minus 6 small segments, the area of the segments being found to be 18 per cent of that of the original circle. All logs are carefully inspected at the mill, and those in which there is evidence of decayed portions or unremoved bark are rejected. Subsequently a man removes the bark and decayed places from these imperfect logs with an ax. The logs are thrown into a large tank of hot water to loosen the ice, dirt, and sand which have adhered to them. They then pass through scrubbers, in which a powerful spray of water removes all the sand and cinders. They are then ready for the chipper. This machine consists essentially of three knife blades in a rapidly revolving vertical steel disk. One end of the log is pressed against these blades at an angle, and in a few seconds the log is reduced to chips. The resulting fragments are then run over screens to separate them into three portions. Everything that passes through a ¼-inch mesh is discarded. This chip dust is at present practically a waste product, though it is used to some extent for packing ice and for bedding horses. A half-day test at the Mechanicsville mill showed that 1,375 pounds of chip dust, or about 2.7 per cent of waste, resulted from chipping 17 cords of wood. The chips which do not pass through a 1-inch mesh are next separated and passed through a machine known as a shredder. This machine, working on a novel principle, crushes the large chips into shreds and separates the good wood from the knots to a large extent. The shredded mixture is then "floated" over a long water tank, in which the knots, by virtue of their greater specific gravity, sink to the bottom. The separation here is almost complete, and the removal of the knots at this time is of great benefit, as they interfere seriously with subsequent operations. The middle portion of the chipped mixture, which is retained on a ¼-inch screen and passes through a 1-inch screen, goes directly by belt conveyors to the storage bins over the digesters, as does also the floated portion of the shredded chips after a second screening. The chips are now ready for the digester.

THE ACID LIQUOR.

The solution of chemical reagents used in the digester to dissolve out of the wood all intercellular and other noncellulose matter consists essentially of calcium and magnesium bisulphites with an excess of free sulphurous acid. It is made by passing sulphur dioxide through a suspension of milk of lime made from dolomitic lime, or through towers of limestone over which water is trickling. The former process is in most general use in this country. A suspension of slaked lime (milk of lime) is made, having a strength of about 1.2° B.—that is, about 1.3 per cent $Ca(OH)_2$. Gaseous sulphur dioxide is prepared either by roasting pyrite or by burning sulphur directly in specially designed burners. The gases are passed through lead pipes submerged in large tanks, through which cold water is running, as it is essential to keep the absorption apparatus as cool as possible. The cooled gas next goes into a tank of milk of lime, which is nearly saturated by allowing the gas to enter at the bottom and to bubble up through the liquid. The unabsorbed gas is conducted from the top of this tank to the bottom of a second tank filled with fresh milk of lime, where the absorption is completed. The residual gases then pass to the pumps, which maintain a partial vacuum in the tanks and insure a constant flow of gas. During absorption the contents of the tank are constantly stirred. When the acid liquor in the first tank is of the requisite strength, as shown by analysis, it is pumped into the acid storage tanks, the second tank is emptied into the first, and fresh lime is added to the second. The process of absorption is then repeated. The composition of the acid liquor varies in different mills and even in the same mill from time to time as the quality of wood varies. A specimen analysis of the liquor, expressed in the mill terms, showed free sulphur dioxide, 2.5 per cent; combined sulphur dioxide, 1.1 per cent; a total of 3.6 per cent. "Free sulphur dioxide" is the total acidity of the solution expressed as SO_2. It is therefore the free dissolved gas plus one-half the sulphur dioxide present as bisulphite. The "combined sulphur dioxide" represents the rest of the bisulphite radicle. The actual composition of the liquor is therefore as follows, the total base being regarded as calcium:

Analysis of sulphite liquor.

	Per cent.
Calcium (Ca)	0.7
Sulphur (S)	1.8
or, in combination—	
Calcium bisulphite ($CaH_2(SO_3)_2$)	3.5
Dissolved sulphur dioxide gas (SO_2)	1.4

For one charge of a digester of average dimensions, 12.8 by 34 feet, producing about 7 tons of dry pulp at each "cook," 16,000 gallons of acid liquor are used.

THE DIGESTER.

The digester consists of an upright steel cylindrical shell with a conical bottom and a nearly hemispherical top, lined with lead, within which is another lining of resistant glazed brick, pointed with a special mortar. Older forms of digesters have concrete linings. The inside dimensions of a digester of average size are, diameter 12.8 feet, total height 34 feet, and its capacity is about 2,700 cubic feet.

THE "COOK."

About 12 cords of wood chips are first placed in the digester, and then about 16,000 gallons of the acid liquor are run in, filling the digester within 6 feet of the top. The shell is then closed tightly and steam is admitted. The contents are brought rapidly to boiling temperature and then the pressure is raised gradually to about 65 pounds, two hours being consumed in this heating. During the next two hours the pressure is increased more slowly to about 80 pounds. At this point the digester is full of liquor, the water condensed from incoming steam having completely filled the space which was left at the time of filling. In order, therefore, to add more steam it is necessary to "relieve." This process consists in allowing the liquor slowly to escape from the top of the digester as steam enters at the bottom. This relief liquor is strongly acid, and as a rule is returned to the acid-liquor tanks to be used again. There is some objection to such recovery of the relief, because it is rather dark colored and is apt slightly to color the next "cook." The temperature is carefully noted and frequent analyses of the liquor within the digester are made during the "cook," especially during the last two hours. Small samples for analysis are drawn from a tap in the side of the digester near the top. They are examined for total sulphur dioxide and the color and odor are noted. If in the opinion of the attendant the reaction is proceeding too fast, the incoming steam and the relief are both shut off and the "cook" is "held." It is intended to complete the "cook" in about six hours. Nearly at that time the sulphur dioxide content begins suddenly to fall, the color becomes darker, and a peculiar characteristic odor develops. The reactions at that time are proceeding very rapidly and the charge must be blown immediately or a dark-colored stock will result. The skill of the operator is here well shown in bringing about this rather sharp end point at almost the exact time desired, six hours. A large blow-off valve is then opened at the bottom of the digester and its entire contents are blown under full pressure into the blow pit, which is a large covered wooden tank, 22 feet in diameter and 20 feet deep, provided with a large air shaft for the escape of the steam and gases. Opposite the end of the pipe leading from the digester there is a bronze baffle plate, against which the contents of the digester are thrown with great force. The pit is provided with a false bottom and the liquor is rapidly drained off. It is essential at this point to remove all the acid liquor as rapidly as possible. After the blowing the liquor darkens rapidly from a light-garnet shade to nearly black, and its retention in the pulp results in a dark-colored product. About 15,000 gallons of wash water are added as soon as possible and drained off. A second washing is then given with the same amount of water, when the drains are closed, more water is added, and the stock is ready to be pumped to storage tanks. A small amount of the acid liquor is taken out during the "cook" as relief, but the principal part of it is discharged at the end of the "cook," constituting the sulphite pulp waste liquor.

SCREENING AND WASHING THE STOCK.

The two processes of screening and washing the stock are carried on simultaneously, and can best be described together. The stock is pumped from the blow pit into storage tanks, from which it is pumped as fast as needed into an elevated tank, flowing thence to the screens and the washing machinery. It first passes through a long revolving cylindrical screen, slightly inclined from the horizontal and provided on the inside with a continuous worm-shaped vane. This screen is very finely meshed, and its function is to remove a large part of the water from the stock. Next the stock passes into a similar cylinder with rectangular meshes about one-fourth of an inch wide and 1 inch long. The wood fiber is washed through these meshes by the aid of a stream of water playing from above. All knots and undigested chips are retained in this screen, collected at its open end, and measured, the amount and character of the undigested portions being regarded as a valuable criterion of the care with which the preceding processes have been conducted. On the average, there will be about 4 cubic feet of this material per "cook," or a little over half a foot per ton of dry pulp. The stock passes from these screens to the settling tanks or "rifflers," long troughs about 6 feet wide and 2 feet deep, provided with baffles on the bottom for the retention of sediment. The object of the tanks is to remove by sedimentation any sand or grit which may have gained access to the stock from the machinery or otherwise. The stock is now ready for the final screening, by which it is separated into marketable stock and tailings. The tailings from the first screening process are generally run through a second screen and a little good fiber is saved in that way. The final tailings are passed over a wet machine and felted into low-grade pulp, which is sold for use in the manufacture of leather board. The screened pulp also is passed over a wet machine, which is essentially a revolving screen that separates the bulk of the water from the pulp, leaving the latter in a rather thick sheet. If the pulp is to be sold or used as unbleached pulp, it is taken from the wet machine at this point, passed between large wooden rollers, and finally removed in the form of thick sheets of wet pulp. If it is to be bleached, it is removed mechanically from the rolls of the wet machine, mixed with a large volume of water, and conducted to the bleach tanks.

BLEACHING THE STOCK.

The unbleached pulp as it comes from the wet machine has a very slight brownish color, although it appears pure white to the inexperienced eye. If such pulp is made into paper, however, it is likely to darken rapidly with age and drying, so that pulp for high-grade papers must be bleached with chloride of lime. Commercial chloride of lime, or bleaching powder, consists mainly of calcium hypochlorite, and it is made by passing free chlorine gas over quicklime. The trade name, chloride of lime, is therefore a misnomer. A typical analysis, by Wagner,[a] of bleaching powder of good quality is given herewith:

Analysis of chloride of lime.

Calcium hypochlorite ($2CaOCl_2+H_2O$)	82.65
Calcium carbonate ($CaCO_3$)	.95
Calcium chloride ($CaCl_2$)	.44
Calcium hydrate ($Ca(OH)_2$)	6.80
Water (H_2O), free	9.82
	100.66

Inasmuch as the chlorine alone of the hypochlorite is available for bleaching purposes, a sample of bleaching powder having the above analysis would contain 43 per cent of "available" chlorine and would be called a 43 per cent bleach. The product on the market seldom contains so much chlorine as that, good grades in this country running from 35 to 40 per cent available chlorine.

The bleaching powder, or "bleach," as it is called in the mill, is received in large iron casks, each holding about 600 pounds. They are emptied into a mixing tank with approximately 3 gallons of water to a pound of bleach. Generally, an ordinary tank provided with a rotary agitator is used for this mixing, but at the Mechanicsville mill an improved mixer is in service, which appears to be very efficient. The tank is conical in shape, about 15 feet high and 10 feet in diameter at the top, tapering to a point at the bottom. A centrifugal pump with a 3-inch discharge is near the tank at its bottom level. This pump withdraws the liquid mixture from the bottom of the tank and discharges it horizontally into the upper part in a direction tangential to the periphery. Circulating the liquor through the tank in this manner produces an immense vortex, so that, although the liquor whirls about the sides of the tank to the level of the inlet, one can look down into this vortex almost to the bottom of the tank. This process accomplishes a thorough mixing of bleach and water in a comparatively short time. The mixture then flows into a large brick settling tank and is allowed to settle until a clear liquor can be decanted. This liquor is tested for strength with a Baumé hydrometer and is mixed with the proper amount of a weak bleach extract to give it the required strength of about 3° B. This weaker solution is made by a second extraction of the sludge or "grout" remaining after the first decantation. The grout is usually strengthened by the addition of a small amount of fresh bleach, agitated with a fresh supply of water, and again submitted to sedimentation. The liquor obtained constitutes the weak bleach mentioned above, while the sludge remaining, the "second grout," is agitated a third time with fresh water and again settled. The third lot of supernatant liquor constitutes the water used in the first extraction of a new lot of bleach; the "third grout" is a waste product. Reference to the analysis already given will show that it consists essentially of calcium hydrate, with more or less carbonate of calcium and other impurities derived from the original lime from which the bleaching powder was prepared.

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[a] Wagner, R. von, Manual of chemical technology; trans. from 13th German ed. by Sir William Crookes, New York, reprint of 1904, p. 360.

The bleach solution of about 3° B. is mixed with pulp in the proportion of about 30 gallons of solution to 100 pounds of pulp.[a] The mixture is passed successively through a series of tanks, eight in number, in which it is brought to and maintained at a temperature of about 100° F. and is mechanically stirred. Tests of this mixture are constantly being made as it passes from each tank to the next, and additional bleach solution is added as required, the processes being so regulated that, after the complete treatment, requiring about six hours' time, the pulp will be satisfactorily bleached and the bleach will be exhausted as completely as possible. It is next necessary to wash out of the pulp mixture the residual bleach and the calcium chloride resulting from the process. This is accomplished by first passing the stock under a series of washers. A washer is essentially a frame, in the form of an eight-sided prism, covered with fine-meshed copper gauze, and mounted on a horizontal axis, so that it is about half submerged in the pulp. It rotates slowly in the direction of the moving stream of stock, and as the water passes through the gauze it is collected in buckets suitably arranged within, elevated to a position above the center line of the box, and discharged through a side outlet. By this means a considerable volume of water is separated from the stock. Fresh water is admitted after each treatment and the washing is repeated several times, after which the washed stock is passed over a wet machine as previously described. It is then either pressed into sheets of wet pulp or, if it is to be used at once in the mill, is removed from the rolls by a stream of fresh water and run directly to the paper mill.

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[a] All references to pulp in these processes are to the actual weight of air-dry pulp in the mixture, though the pulp is always mixed with a considerable amount of water throughout the process of manufacture.

SUMMARY.

The various processes described in the foregoing pages have been arranged for convenient reference in diagrammatic form in Plate I. The raw materials that enter into the process are shown along the top line of the diagram in capitals. They are wood, lime, sulphur (or pyrite), bleaching powder, and water. Arranged vertically at the left is a list of the waste and by-products of the process, namely, bark, sawdust, knots, sulphite waste liquor, sand and grit, and sludge or grout from the bleach-solution tanks. Much of the water used in the later processes is returned and used for washing the freshly cooked pulp, so that practically the only liquid waste is the waste acid liquor and the first wash waters, these together making up the sulphite waste liquor. At the bottom of the diagram the finished products of the process are shown, namely, low-grade unbleached pulp and bleached sulphite pulp. Disposal of the grout involves no serious difficulties. It is usually discharged into low-lying fields or into artificially constructed basins, where it is converted into compact masses of carbonate of lime. The small amount of chip dust is readily used in ice houses or as a bedding material for horses. The bark if removed at the mill is either burned or given away for fuel, though it is generally more economical to have the barking done before shipment. In the study of stream pollution, therefore, consideration need be given only to the combined waters resulting from the digestion of the chips and the subsequent washings of the pulp—that is, the liquor here called the sulphite pulp waste liquor.

SULPHITE PULP WASTE LIQUOR.

PREVIOUS INVESTIGATIONS.

This waste, arising as it does from an industry involving elaborate chemical methods and necessarily employing skilled paper-mill chemists, has probably received more careful and systematic study than any other waste product of the present day. A prize of 10,000 marks was offered in Germany in 1894 for the best method of preventing the pollution of streams by sulphite liquor, but it still remains unawarded. Scores of processes for utilizing or purifying the waste have been patented in Germany, England, and the United States, but none of them has been sufficiently successful to relieve, in any noticeable degree, the burdensome situation. Technical literature contains reports of exhaustive researches on the constitution of the organic substances found in this liquor, but there is no satisfactory agreement on this point. No more striking commentary on the difficulty of the problem can be made than the bare statement that, in spite of all these researches, the substance is still classed as a waste product. According to Cross and Bevan,[a] who summarize a paper by H. Seidel,[b] no satisfactory application of this by-product has yet been evolved. Evaporation and combustion involve losses of sulphur.[c] A more complete regeneration of the sulphur has been the subject of a series of patents.[d] The process of V. B. Drewson[e] consists in heating with lime under pressure, yielding calcium monosulphite. The sulphite is redissolved as bisulphite by treatment with sulphurous acid. This process is relatively costly, and yields necessarily an impure lye. It has been proposed to employ the product as a foodstuff both in its original form and in the form of benzoate;[f] but its unsuitability is obvious from its composition. A method of destructive distillation has been patented. Seidel,[g] however, found on investigating the process that the yield of useful products is much too low for its economical development. Fusion with alkaline hydrates for the production of oxalic acid[h] is also excluded by the low yield of the product. The application of the liquor to tanning purposes[i] appears promising from the fact that 28 per cent of the dry residue is removed by digestion with hide powder, but this application has been investigated without practical success. Various probable uses are suggested by the viscosity of the evaporated extract, but as a substitute for glue it has proved of little value. It is also used to some extent as a binding material in the manufacture of briquets and as a substitute for gelatine in the petroleum industry. Cross and Bevan[j] and Mitscherlich[k] precipitate a compound of the lignone complex and gelatine by adding a solution of the latter substance to the sulphite waste liquors. The compound is redissolved in weak alkaline solutions and employed in this form for engine-sizing papers. Ekman has patented a process[l] for "salting out" the lignone sulphonates, the product being resoluble in water and the solution having some of the properties of a solution of dextrin. Owing to its active chemical properties this product, "dextron," has a limited capability of being substituted for dextrin. The suggestion to employ the evaporated extract as a reducing agent in indigo dyeing and printing has also proved unfruitful. Seidel's application of the soda salt of the lignone sulphonic acid as a reducing agent in chrome-

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[a] Researches on cellulose 1895-1900, p. 150.

[b] Zeitschr. angew. Chemie, 1900.

[c] German patents Nos. 74030 and 83438; also Seidel and Hanak, Mitt. Techn. Gew. Mus., 1898.

[d] German patents Nos. 40308, 69892, 71942, 78306, and 81338.

[e] German patent No. 67889.

[f] German patent No. 97935.

[g] German patent No. 45951.

[h] German patent No. 52491.

[i] German patent No. 72161.

[j] British patent No. 1548, 1883.

[k] German patents Nos. 93944 and 93945.

[l] German patent No. 81643.

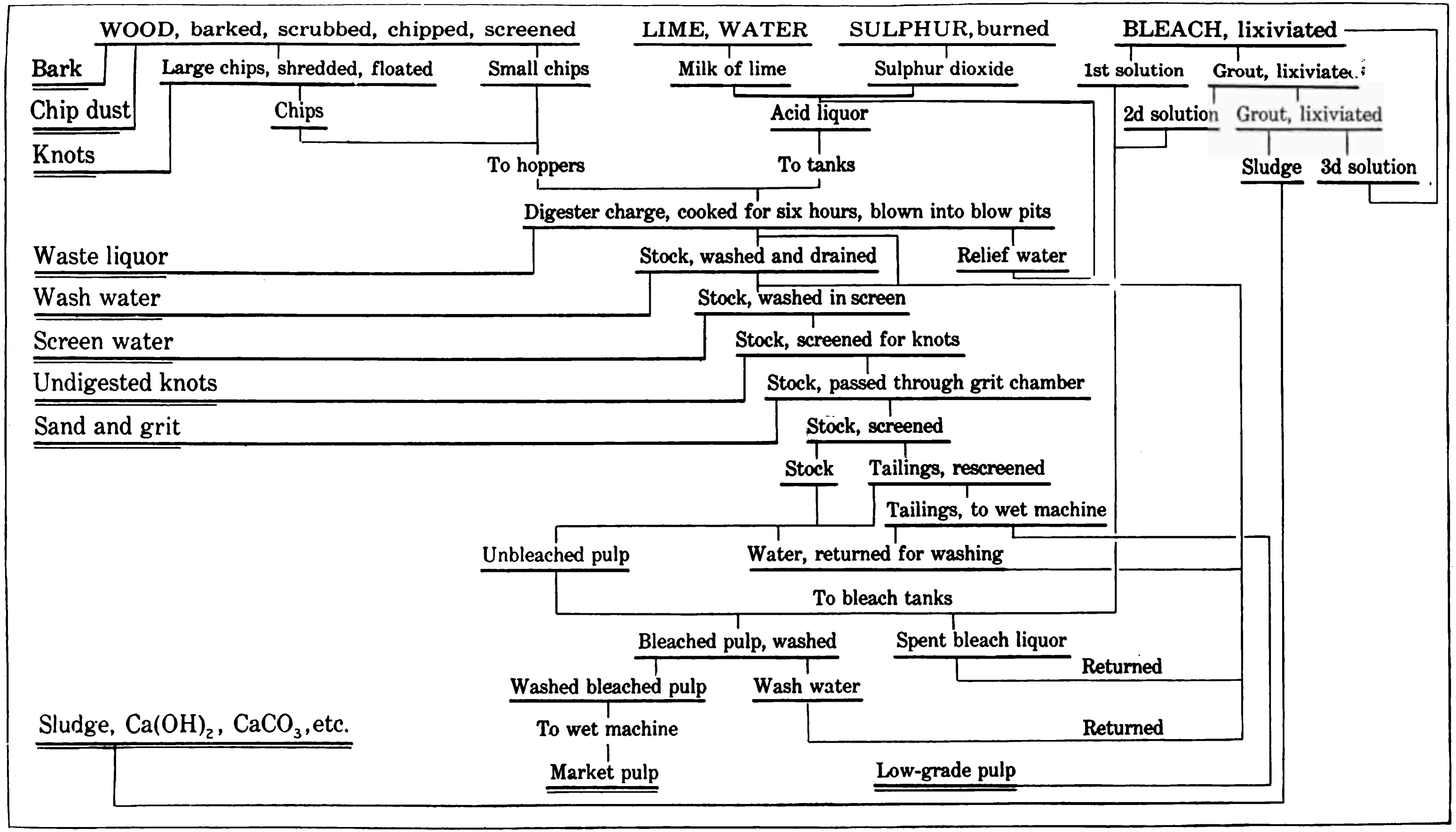

DIAGRAM ILLUSTRATING THE STEPS IN THE MANUFACTURE OF WOOD PULP BY THE SULPHITE PROCESS.

mordanting wool and woolen goods[a] is more successful in practice, and its industrial development shows satisfactory progress. The product is known as "lignorosin." In another place, however, Cross and Bevan[b] comment on this process by calling attention to the fact that such use for a by-product, produced in such enormous quantities, is of relatively small importance.

It is remarkable that the main by-product of the bisulphite process is still for the most part an absolute waste, notwithstanding the many investigations of technologists and attempts to convert it to industrial use. As it represents a percentage of the wood pulped equal to that of the cellulose obtained, it is a waste of potentially valuable material that must be termed colossal. Moreover, as a waste to be discharged into watercourses, it becomes a source of burden and expense to the manufacturer, and with the increasing restrictions on the pollution of rivers it constitutes in many localities a problem to be solved only by the cessation of the industry. The alternative in such cases is dealing with it destructively—that is, by evaporating and burning it. In this treatment the high calorific value of the organic matter appears on the credit side; but, as calcium and magnesium bisulphites are used, the residue from calcination is practically without value. If, however, a soda base is substituted, the alkali is recoverable in such form as to be directly available for the alkaline-sulphide or Dahl process. As a more complicated alternative the soda can be recovered by the old black-ash or Leblanc process, and the sulphur by the now well-established Chance process, in which lime must be added to the concentrated liquors before calcination. The engineering features of the system in respect to evaporating and calcining are the same. Economic working requires (*a*) evaporation by multiple effect and (*b*) calcining on the continuous rotary principle. For the latter process the draft of air is concurrent, by a special device, with the movement of the charge in the furnace, a feature by which a progressively increasing temperature within the furnace is procured. This interesting development has been elaborated by Drewson and Dorenfeldt, to whose publications readers who wish to inform themselves in detail in regard to these developments are referred. The present necessity of a destructive treatment of the sulphite waste liquor being assumed, their scheme has many advantages; sodium bisulphite liquors are more economically prepared and the pulp obtained is superior in paper-making quality and in economy of bleaching to that resulting from the calcium or magnesium bisulphite processes. The soda may be recovered in a form in which it is immediately available as a powerful hydrolyzing alkali in the manufacture of soda pulp, so that these two systems become complementary to one another. The employment of soda as the base also affords a new motive for developing the electrolytic processes of decomposing salt.

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[a] German patent No. 99682.

[b] A text-book of paper making, 2d ed., 1900, p. 143.

Cross and Bevan's comments present an excellent summary of conditions at the close of 1900. Significant of more recent developments in the methods of utilizing or disposing of this waste is the fact that in their second volume of "Researches,"[a] a treatise purporting to review all work of importance on cellulose industries during the years 1900–1905, these authors make no mention whatever of the sulphite waste problem.

AMOUNT OF WASTE PER TON OF PULP.

It is now practicable to inquire more carefully into the amount of the waste and its general characteristics. The important facts to be considered in any discussion of stream pollution are the amount and the character of the polluting material independent of the amount of water in which it may be carried. Chemical analyses of the waste liquor in connection with accurate determinations of its volume would furnish the requisite information, and such procedure is usually adopted. In the present case, however, it happens that the amount of polluting material bears a definite relation to the total product of the mill in pulp, independent of slight modifications of the process, whereas the amount of diluting water varies greatly in different mills and even from time to time in the same mill. For example, some mills use the old-fashioned rotary digesters, in which it is not necessary to use more than half the amount of water in the acid liquor that is used in upright digesters. The washing process is often conducted at places where water is plentiful, with a total disregard of economy in water, while in other mills strict economy of water is necessary; therefore the concentration of the waste liquors may be three or four times as great in one case as in another. In view of these facts and of the statement made above, that a definite amount of polluting material is produced for each ton of pulp turned out, it appears that the best procedure is to determine the definite relationship between the amounts of pulp and solid waste. Results obtained at one mill are applicable to any mill using a similar process, though the actual volumes of the wastes may be greatly different. After having determined this fundamental relation, it is of interest to compare the figures obtained with actual analyses of the waste liquor. Such comparison will give an approximate measure of the volume of diluting water.

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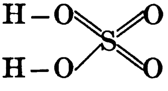
[a] Researches on cellulose, 1900–1905.

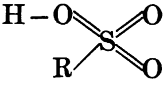
A cord of spruce wood ordinarily handled at the mill will weigh about 3,600 pounds, of which about 55 per cent, or 2,000 pounds, is actual wood substance, the remaining 45 per cent being water. The amounts of chip dust, knots, etc., which are really insignificant as compared with the total weights, may be neglected in this calculation. About 1,100 pounds of so-called "air-dry" pulp having 10 per cent water, or, roughly, 1,000 pounds of actually dry pulp, is made from 1 cord of wood. Therefore the production of 1 ton of pulp is accompanied by the production of an equal amount of waste organic material that is discharged in the waste liquor. According to the analysis on page 10, the sulphite liquor contains 0.7 per cent of calcium and 1.8 per cent of sulphur, equivalent, respectively, to 0.058 pound and 0.150 pound per United States gallon. On the basis of 16,000 gallons of acid liquor to a digester charge, which produces 7 tons of air-dry pulp, each ton of pulp is represented by 132 pounds of calcium and 343 pounds of sulphur. About 0.1 per cent of sulphur dioxide, or 9 pounds of sulphur per ton of pulp, is left unoxidized at the end of the "cook." Of the remaining 336 pounds of sulphur 10 per cent may be allowed for loss of free sulphur dioxide in the relief, leaving approximately 300 pounds of sulphur which has been oxidized in the process. The first product of this oxidation is probably sulphuric acid, according to the following equation, the oxygen being derived from the wood during the digestion:

$$SO_2+O+H_2O=H_2SO_4.$$

This presents the simplest idea of the digestive action. Sulphurous acid is oxidized to sulphuric acid with a corresponding reduction of the wood substance. The fate of the sulphuric acid thus formed has not been satisfactorily determined. It is known that in the final product there is little free sulphuric acid. The first effect of its formation would be the precipitation of calcium sulphate, probably on the wood fibers. As magnesium sulphate is soluble, this is probably the reason why dolomitic lime gives such excellent results. If, however, all the calcium or magnesium originally used were converted to sulphate, there would be needed for that reaction only 100 pounds of sulphur, leaving still 200 pounds of sulphur unaccounted for. It will be shown when the chemical nature of the waste is considered that, according to prevailing views, the sulphuric acid from this amount of sulphur again reacts with a portion of the wood substance to form a so-called sulphonic acid. This may be regarded as sulphuric acid in which one of the OH groups has been replaced by an organic radical (R) thus:



Sulphuric acid.



Sulphonic acid.

This reaction is not complete and a small amount of sulphuric acid is generally left in the liquor. For the present it will not be necessary to discuss the relative amounts of these two acids. The waste material resulting from the digestion of sufficient wood to make 1 ton of pulp may be summarized as follows:

Materials in the waste liquor per ton of pulp.

	Pounds.
Wood material	2,000
Calcium sulphate	449
Sulphur dioxide (omitted from total)	18
Sulphur in sulphuric acid and in organic combination	196
Total solid matter	2,645

CHEMICAL COMPOSITION OF THE WASTE LIQUOR.

As has been stated, the actual strength of the waste liquor is entirely a matter of dilution. The 16,000 gallons of acid liquor used in the "cook" producing 7 tons of air-dry pulp is usually diluted with one to two times its volume of water in the blow pit, and other wash waters later mingle with this liquor in the drains. For the purpose of study, however, it is advisable to procure samples of the undiluted waste liquors directly from the digester, because in any plan for the recovery of this liquor it will undoubtedly prove advantageous to separate the undiluted liquor. For the investigation here reported samples of the liquor were collected from the bottom of the digester just before blowing. The hot liquor was drawn into a barrel, allowed to cool, and then bottled in carboys for future use. The subjoined table gives analyses of this liquor and the figures of several analyses of similar liquors by other chemists.

Analyses of sulphite pulp waste liquor.

[Grams per liter.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Total solids	95	82	88	85	93	92	109	52	64
Loss on ignition	82	68	75	69	81	......	90	45	56
Ash	13	14	13	16	12	......	19	17	8
Analysis of ash:									
Calcium (Ca)	2.2	......	......	......	......	......	6.9	1.76	2.08
Magnesium (Mg)	1.2	......	......	......	......	......	.18	.97	1.26
Sulphur (S)	2	......	......	......	......	......	......	......	......
Total sulphur	10.5	......	......	......	......	9.2	......	......	......
Free sulphur dioxide (SO_2)	1	2.6	2.2	2.9	2.6	3.8	......	.94	.90
Sulphite radicle (SO_3)	......	7.3	7.9	6.7	1.2	3.8	3.8	1.10	1.36
Sulphate radicle (SO_4)	......	4.1	5.4	4.8	2.7	1.9	7.2	[a]9.27	[a]11.10
Oxygen consumed	36	52	52	50	60	......	......	......	......
Specific gravity	......	......	......	......	......	......	......	1.024	1.028

[a] Exclusive of the organic S.

No. 1, by the writer, is the average of two analyses of waste liquor collected directly from the digester at the Mechanicsville mill. Nos. 2 to 6, inclusive, are quoted by Hoffmann;[a] Nos. 2, 3, 4, and 5 being by Wickelhaus,[a] and No. 6 by Lehman. No. 7 is given by Schubert,[b] and Nos. 8 and 9 are taken from the notebook of S. C. Lindberg, paper-mill chemist, who has kindly permitted their use.

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[a] Hoffmann, C., Practisches Handbuch der Papier Fabrikation, Berlin, 1897.

These analyses give an excellent idea of the general character of the liquid. The proportions of the various constituents are in agreement with the figures which have been calculated from the amounts of raw materials used. The analyses also determine satisfactorily the nature of the inorganic matter in the waste and show the relatively large amount of organic matter present, about 80 per cent of the total solids.

CHEMICAL NATURE OF THE ORGANIC MATERIAL.

Thus far only the total amount of waste material in the liquor resulting from the digestion of 1 ton of dry pulp and its division into organic and inorganic constituents have been considered. The chemical nature and the essential characteristics of the organic matter deserve further consideration. Though our knowledge of the chemistry of wood is not extensive, the following facts seem to be definitely settled and may be accepted as embodying all that is positively known. The wood substance itself, freed from the relatively small amount of intercellular matter, such as gums and sap constituents, is a homogeneous material of fairly constant composition. To this substance chemists have given the name ligno-cellulose. Ligno-cellulose can be broken down by suitable chemical treatment into two or more substances. These are cellulose, which is the material of the wood pulp, and a complex substance or mixture variously called lignose, lignin, or lignone. It is this latter body or mixture of bodies which in the sulphite process is supposed to be sulphonated, giving rise to a substance known as lignon-sulphonic acid. The constitution of this substance is not known, nor is its chemical identity even assured. Beyond these meager facts all is hypothesis, despite the large amount of experimental work which has been done on the substance under discussion. Probably the best estimate of the character of lignone is given by Cross and Bevan,[c] who made an exhaustive study of the subject.

They conclude that it is a single substance made up of (*a*) $2C_{18}H_{18}O_{10}$, a ketone transitional to quinone which chlorinates directly to marriogallol; (*b*) $6C_5H_4O_2$, furfural, in combination by condensation with (*a*) and (*c*); and (*c*) $5C_2H_4O$, acetic residue. The simplest empirical formula for their lignone is $(C_6H_6O_3)n$, *n* being not less than some multiple of 24. Tollens[a] gives as the result of his analysis of the sulphonated form the empirical formula—

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[a] Papier Zeitung, 1895, No. 38.

[b] Schubert, Max, Die Cellulose Fabrikation, Berlin, 1892.

[c] Cross, C. F., and Bevan, E. J., Contributions to the chemistry of lignification: Jour. Chem. Soc., vol. 15, trans., 1889, p. 199.

$$C_{24}H_{23}O_7(OCH_3)_2.(SO_3H).$$

This formula must be slightly modified in view of Cross and Bevan's satisfactory determination of the presence of 5 acetic residues in the C_{76} molecule, instead of 6, as given by Tollens's formula. It has been stated that the chemical identity of the sulphonated form has never been satisfactorily shown. The experimental work on sulphite liquor, conducted by the author, seems to prove that the substance in question is probably not a true sulphonic acid.

PURIFICATION OF SULPHITE WASTE LIQUOR.

Investigations on the disposal of waste liquors may be carried out either with the object of recovering and utilizing the material contained therein or with the simpler aim of purifying the liquid so that it may safely be discharged into a stream. The former method of investigation has appealed most strongly to manufacturers and chemists, and a great many attempts have been made to discover some useful by-product in the waste sulphite liquors. Reference to these investigations will be made later. Owing to the failure in general of all such attempts and to the stringent laws against stream pollution, particularly in Germany, some attempts have also been made simply to purify the liquor by precipitating the organic matter, the experiments having no reference to the recovery of valuable by-products. One of the earliest of these investigations was made by H. Frank,[b] who gives the following composition of the sulphite waste which he used:

Composition of sulphite waste.

	Grams per liter.
Total solids	82
Loss on ignition	59
Ash	23
Calcium (Ca)	5.3
Magnesium (Mg)	.25
Sulphate radicle (SO_4)	14.4

In the process developed by Frank the liquor is treated first with lime to neutralize the free acid and then with chimney gases to carbonate the excess of lime and oxidize the calcium sulphite. A heavy precipitate of sulphate and carbonate is formed and it is claimed that much of the organic matter is dragged down, so that the supernatant liquid could be discharged into the stream. This process was later investigated more thoroughly by F. B. Ahrens, E. Klingstein, and P. Schubert,[c] who state that many German wood-pulp mills have been compelled to close because it was found impossible o comply with the requirements of rivers-pollution officials. The xamination of the waste sulphite liquor which they used showed that it gave a strongly acid reaction, had a specific gravity of 1.0465 at 15.8° C., and was optically inactive. The dry residue was 9.4 per cent, of which 1.11 per cent was ash and 8.29 per cent organic matter—not strictly accurate determinations. The liquors from the digesters were nearly neutralized by passing them over limestone. The hot ye was then mixed with a known quantity of fresh lime water once boiled, filtered, and the filtrate neutralized with carbonic-acid gas. The results obtained are shown in the following table:

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[a] Quoted by Cross and Bevan, Researches on cellulose, p. 126.

[b] Wien. Jahresbericht, 1887, p. 1177.

[c] Zeitschr. angew. Chemie, 1895, p. 41.

Results of experiments in neutralizing hot sulphite waste liquors.

CaO added.	Analysis of supernatant liquor.		
	Dry substance.	Ash.	Organic matter.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
2	8.75	1.80	6.95
3	7.48	1.59	5.89
4	7.36	1.71	5.65
5	7.13	1.56	5.57
6	6.86	1.52	5.34
7	6.74	1.58	5.16
8	6.65	1.54	5.11
9	6.61	1.57	5.04
10	6.79	1.51	[a] 5.28
11	6.54	1.55	4.99
12	6.52	1.49	[a] 5.03
15	6.31	1.49	4.82
20	7.00	1.60	[a] 5.40
30	4.99	1.01	3.98

[a] Organic matter rendered soluble again by boiling.

When the liquors were treated cold, the following results were obtained:

Results of experiments in neutralizing cold sulphite waste liquors.

CaO added.	Analysis of supernatant liquor.		
	Dry substance.	Ash.	Organic matter.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
2	6.21	1.11	5.10
3	6.19	1.33	4.96
4	5.26	1.00	4.26
6	5.08	1.04	4.04
8	4.96	1.10	3.86
10	5.67	1.22	4.45
12	5.76	1.23	4.53
14	6.26	1.29	4.97

Sodium aluminate was also tried as a precipitant, but the results were less satisfactory. The precipitated and neutralized liquors were then treated electrically. A current of 5 amperes and only sufficient potential was passed through the liquid between platinum electrodes, but no diminution in either mineral or organic matter was observed after two hours. A high-tension current (106 volts) was then tried, but the results were equally ineffective after a test of the same duration. It is evident, these authors conclude, that the objectionable organic matter, if removable at all, calls for some process hitherto undiscovered. Ahrens tried, unsuccessfully, to treat this waste bacterially after neutralization on the lines of his patent. It was found absolutely sterile to begin with, and the amount of bacterial filtration required for its decomposition was altogether impracticable. E. Bruch[a] found that if the waste liquors are treated when acid, or neutral, with leather glue, a compound of tannic acid and glue is formed which coagulates on storing and becomes highly viscid. If then the clear, colorless top liquor is decomposed with aluminum sulphate, another gummy precipitate is formed. Both precipitates are soluble in alkalies and in weak ammonia, and may be removed, dried, and powdered. If the clear liquor is then neutralized with chalk or lime, a precipitation and clarification ensue, and the top liquor is free from smell and has lost about 25 to 30 per cent of the total organic constituents, and these the most easily decomposable.

UTILIZATION OF SULPHITE WASTE LIQUOR.

By far the most important work on this waste liquor has had fo its object the utilization of the organic matter. Its complex chemical nature and relatively large amount and the fact that it is stil a chemical mystery make the field particularly inviting for research In some interesting laboratory experiments made by Buddens. and quoted by Griffin and Little,[c] the waste liquor was neutralize by ammonia, the lime was precipitated by ammonium carbonate and the carbonate of lime thus formed was separated by filtration The dark-brown filtrate was evaporated and the dried residue dis tilled. The dried residue contained 7.2 per cent of ammonia a salts. Water and a yellow oil were obtained in the condenser, an finally a crystalline sublimate appeared on the walls of the tube The escaping gases were caught in a gasometer. The oil had at firs a mercaptan-like odor, but this disappeared on heating slightl The odor was without doubt due to organic sulphur compound which were present in traces. The mixture of oil and water wa after this heating, distilled with steam, the distillate was shaken ou with ether and then dried, and the ether was evaporated over cal cium chloride. The brown oil that remained boiled at 130° C., an as it colored a pine chip moistened with hydrochloric acid a stron carmine, it was believed to be pyrrol. Pyrocatechin was also found in the distillate, as was proved by color tests with iron salts and by the reduction of Fehling's solution. The gases from the first distillation were carbon monoxide, hydrogen, marsh gas, and hydrogen sulphide. Four hundred grams of the residue yielded 180 grams of coke, 30 liters of gas, and 200 grams of distillate. Mucic and saccharic acids could not have been present as such in the liquor, because they are formed by the oxidation of carbohydrates, and the action of the liquor is a reducing one. Yet pyrrol is formed by distilling the ammonium salts of these two acids. The only way of accounting for pyrrol is by considering that succinic acid is formed from the resins in the wood—a not improbable assumption. Ammonium succinate changes readily into ammonium succinamide, which gives pyrrol when it is heated with reducing agents. The presence of pyrocatechin is due to the presence of dioxybenzoic acid (1, 3, 4), which is in the liquor as dipyrotechnic acid. The decomposition of this acid by distillation with ammonia produces tannic acid and pyrocatechin. Doctor Buddens states that there is no tannic acid in the liquor, which will give a blue-black color with ferric chloride, because the tannin in wood is reduced by digesting with sulphurous acid. The reduction is probably due to dipyrocatechuic acid, but by treating the liquor with ammonia and distilling, tannic acid is eventually formed. Sulphites are oxidized to sulphates when the tannin is reduced. It is possible, therefore, that the difficulty of pulping wood rich in tannin by the sulphite process is due to the action of the tannin, which renders the sulphurous acid ineffective. Lindsey and Tollens,[a] in their systematic search for the different sugars, used liquor from a Mitscherlich slow-process cook, with a specific gravity of 1.055, showing total solids 9.5 per cent, and calcium 0.41 per cent. The solution was pale yellow in color and strongly reduced Fehling's solution. They found no evidence of the presence of saccharose, dextrose, or dextrose-yielding sugars, traces only of levulose or levulose-yielding sugars, and but a small amount of galactose. On the other hand, mannose, determined as a hydrazine, was found to represent 6 to 7 per cent of the original total solids. Furfural was found in some quantity on heating with hydrochloric acid, and xylose was identified in the solution. Alcoholic fermentation of the liquor gave amounts of alcohol corresponding to only 1.2 per cent of the total carbohydrates. The remaining gummy mass behaved as a homogeneous complex, yielding several synthetic preparations, the analyses of which were consistent with the view of its homogeneity.

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[a] Die Abwässerreinigung der Cellulose-Fabriken und die Papierleimung: Chem. Zeitung, 1892, p. 1782.

[b] Buddens, W., Papier Zeitung, March, 1891.

[c] Griffin and Little, Chemistry of paper making, New York, 1894.

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[a] Liebig's Annalen, No. 267, 1892, p. 341. Abstracts Jour. Chem. Soc., 1892, p. 802.

A summary of various attempts to recover valuable products from the waste has already been given (pp. 15–18). Thus far no satisfactory recovery of valuable chemical substances has been made. The substance itself has been used as a substitute for glue and for sizing. Mitscherlich precipitated the tannin compounds with glue in the presence of alum and sulphuric acid, obtaining a rubbery mass, soluble in weak alkali, which could be used in engine sizing. He later improved the process[a] by precipitating with lime to remove the sulphite present and then diffusing the liquor through membranes. The diffusible portion contained sugars and was fermented for alcohol. The nondiffusible part was treated as described above in order to remove the tannins. A later patent[b] describes a process in which, after the removal of the calcium salts, the liquor is heated with hair or bone to give a semiwaterproof sizing. V. Drewnen and L. I. Dorenfeldt[c] treat the liquor with soda ash recovered from the soda pulp process, precipitating the lime and a part of the organic matter. They draw off the clear liquor and burn the residue, using the heat of the combustion to evaporate more liquor. The liquor is said to contain more calorific energy than is necessary to evaporate it. The soda ash is recovered from the residue by the usual process, and about 60 per cent of the sulphur is recovered by liberating free sulphur dioxide with carbon dioxide gas. The fumes and the gases from the evaporation were found to be very corrosive. This trouble was finally overcome by combining the wastes of the sulphite and soda pulp mills and treating them like soda wastes. Frank's process, as described by Schubert,[d] consists in precipitating the remaining calcium bisulphite as normal sulphite with excess of lime, after which the precipitate is redissolved in an excess of sulphur dioxide. Such treatment would recover only a small part of the total sulphur. Meyer's process, also described by Schubert,[e] seeks to recover valuable products by destructive distillation of the organic material in the waste. The liquors are neutralized, concentrated to a thick sirup, mixed with charcoal to a paste, and distilled. The yield of valuable products is too small to make the process economical. H. Seidel has employed the soda salt of the lignone sulphonic acid as a reducing agent in chrome mordanting wool, where, under the name "lignorosin," it is used in place of tartaric and lactic acids.[f] The material, especially when concentrated, is very sticky, and many attempts have been made to utilize it as a substitute for glue. In J. S. Robeson's process[a] for the manufacture of an adhesive, which is being used at Ausable Forks, N. Y., by a large mill,[b] the waste liquor is neutralized with lime and evaporated in vacuo. The product is a thick, molasses-like fluid, which finds application in foundries as an adhesive in core making. C. H. Voight[c] makes a glue substitute by heating starch and a peroxide with the sulphite liquor. A. G. Brooks[d] evaporates the liquid till it contains 20 per cent water, then adds carbohydrates or albuminoids and dries the mass, which is used for fuel, pitch, glue, resin, or size. Knoesel[e] concentrates to 25° B. and treats with a slag meal high in phosphorus (Thomas slag). It is claimed that the phosphorus of the slag is rendered soluble in citrates and becomes available in fertilizing. Ahrens[f] investigated the process and could not substantiate its claims. Processes have been proposed for the destructive distillation of the substance, and, as has already been stated, both pyrrol and pyrocatechin have been obtained in this manner. The yield of these products has not been sufficient to make the process successful. Patents have been granted for processes involving the use of the liquor in tannin.[g] According to Seidel[h] 28 per cent of the solids are removed by rawhide powder. No satisfactory method has yet been described for separating the tannin substance from the remainder. This seems to be one of the important lines for future investigation. Morterad[i] subjects the hot liquors to a partial vacuum and removes from them a considerable volume of sulphur dioxide. Bergerhopf[j] made a cheap grade of paper for newspapers by using the waste liquors to digest sawdust. Eckman[k] "salts out" the liquors and makes a concentrated solution, which he calls "dextrone," a substitute for dextrin, or British gum.

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[a] United States patent No. 681241, 1901.

[b] United States patent No. 687844, 1901.

[c] United States patents Nos. 620755, 1899, and 726036, 1902.

[d] Schubert, Max, Die Cellulose Fabrikation, Berlin, 1892.

[e] Op. cit.

[f] Rev. gén. des mat. col., vol. 2, 1898, p. 370. Jour. Soc. Chem. Ind., vol. 17, 1898, p. 1043. British patent No. 19005, 1897. German patent No. 99682, 1897.

EXPERIMENTAL INVESTIGATIONS WITH THE ORGANIC MATERIAL.

The knowledge of the chemical reactions which characterize lignone is very meager. Early in the present study it was deemed important to obtain additional light on the general behavior of this material. It was hoped that in this way knowledge of its chemical nature might be enlarged and particularly that some reactions of industrial value might be discovered. For this study preparations of the dry material were made in various ways; the solubility of these preparations was investigated; attempts were made to identify a sulphonic acid in the material; and various other reactions were studied.

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[a] United States patent No. 833634, 1906.

[b] Paper Trade Journal, Jan. 5, 1905, p. 12.

[c] United States patent No. 770202, 1904.

[d] British patent No. 8088, 1901.

[e] Jour. Soc. Chem. Ind., 1902, p. 489.

[f] Chem. Zeitung, vol. 4, 1905, p. 40. Chem. Centralbl., vol. 1, 1905, p. 700. Jour. Soc. Chem. Ind., vol. 14, 1905, p. 343.

[g] German patent No. 72161.

[h] Zeitschr. angew. Chemie, 1900, p. 951.

[i] United States patent No. 833936, 1906.

[j] German patent No. 160651, 1903. Jour. Soc. Chem. Ind., vol. 24, 1905, p. 1028.

[k] German patent No. 81643.

PREPARATION OF CRUDE "LIGNONE."

Three different preparations of the dry material were used. "Lignone A" was obtained in dry form at the mill. It was observed that certain steam pipes passing near the blow pit were heavily coated with a hard vulcanite-like substance, nearly an inch thick in places. About a pound of this material was chipped off and used in certain of these experiments. "Lignone B" was the supposed calcium compound obtained by evaporating the liquor to one-half volume and salting out with common salt. A granular amorphous substance, containing some salt and moisture, was obtained. "Lignone C" was supposed to be the sodium compound. When the liquor was neutralized with sodium carbonate and allowed to settle, a large amount of calcium carbonate was precipitated. The remaining liquor was evaporated and salted.

SOLUBILITY OF CRUDE "LIGNONE."

The solubility of each of these preparations was tested with several solvents in an endeavor to obtain a liquid from which the material could be crystallized. No solution took place in either hot or cold benzoin, amyl alcohol, allyl alcohol, petroleum ether, amylene, amyl acetate, aniline, toluene, xylene, nitrobenzene, carbon bisulphide, ethyl ether, or benzol. Benzoin seemed to soften the substance. The tests were repeated after acidifying to see if a free acid could be found which would dissolve, but the results were again negative. The two alcohols dissolved the samples if diluted with water. Ordinary ethyl alcohol also dissolved it, a result probably due to the water present. Absolute ethyl alcohol was not tried.

REACTIONS WITH PHOSPHORUS CHLORIDES.

An important general reaction of sulphonic acids is that with phosphorus pentachloride, giving sulphon-chlorides according to the reaction—

$$R.SO_2.OH + PCl_5 = R.SO_2.Cl + POCl_3 + HCl.$$

Sulphon-chlorides are for the most part insoluble oils which combine with ammonia to form crystallizable sulphonamides, as follows:

$$R.SO_2.Cl + 2NH_3 = R.SO_2.NH_2 + NH_4Cl.$$

Appropriate mixtures of the crude "lignones" with varying amounts of the pentachloride, the oxychloride, and mixtures of the two were made. No indication of any reaction was obtained at room temperature or at temperatures up to 180° C., at which point the oxychloride begins to distill. Altogether about twenty attempts were made to bring about this reaction. The products after heating were treated with ammonia, but no evidence of any amide was ever obtained. It must be concluded, therefore, that the "lignone" does not react with the chlorides of phosphorus in the way which characterizes sulphonic acids in general.

FUSION WITH ALKALI.

Another characteristic of sulphonic acids is their ready reduction to corresponding phenols on fusion with caustic alkali according to the reaction—

$$R.SO_2.OH + 2KOH = K_2SO_3 + R.OH + H_2O.$$

Preparations of "lignone" were fused in this way, the resulting masses being extracted with ether and evaporated. Only mere traces of ether extract were obtained, and these gave none of the usual tests for phenols. During the fusion the sulphur gave strong evidence of its escape into the air in the form of some volatile mercaptan, with a very penetrating and sickening odor.

POSITION OF THE SULPHUR IN "LIGNONE."

As in both series of tests just described the "lignone" failed to react in a way characteristic of true sulphonic acids, the presumption is reasonable that a sulphonic acid is not present. An interesting question is therefore raised. How is the sulphur in this material related to the molecule? In the salting-out experiments some light was thrown on this question. It was found that a considerable part at least of the sulphur was in such loose combination that it was given off as sulphur dioxide in the cold during the salting process. The result when first observed was attributed to the sulphur dioxide in the liquor, but it was possible to show that such was not its origin. A small amount of the fresh liquor was cautiously evaporated nearly to dryness and then diluted with water to the original volume. This solution was then salted in parallel with a fresh solution. As nearly as could be determined by the sense of smell, equal amounts of sulphur dioxide were given off by both samples. Confirmatory results were obtained by dissolving some of "lignone A," a completely dried sample, and treating it in the same manner. That all the sulphur could not be removed by this procedure was evident on drying and igniting the salted sample, when the same disgusting odor was given off as by the original sample and apparently to the same degree. This point was verified quantitatively by titration with iodine solution. When the solution was acidified, an evolution of sulphur dioxide occurred and the reducing power increased from an equivalent of 0.01 per cent to 0.104 per cent of sulphur dioxide. On continued boiling without acid the reducing power increased from 0.011 to 0.015 per cent of sulphur dioxide. Boiling with potassium hydrate still further increased it to 0.201 per cent. Lime water had a similar but less marked effect. All these observations point to the probable fact that a sulphurous ether is present. Such ethers yield sulphur dioxide to sulphuric acid and are readily hydrolyzed by an alkali. The results here obtained are, in all respects, what would be expected from sulphurous ether, and the presence of a sulphonic acid has not been verified. Though the presence of the latter compound has not been disproved, the writer is strongly of the opinion that the major part, at least, of the sulphur is present in the form of an acid sulphurous ether of some complex hydrocarbon radicle.

REACTIONS WITH AROMATIC AMINES.

Previous investigators have generally agreed that "lignone" possesses aldehydic properties. A characteristic property of aldehydes is that of forming condensation products with certain bodies; the aldehyde and the other substance—aniline, for example—condense to form a complex molecule. When a solution of "lignone" was mixed with aniline, a bright-red precipitate was formed. An excess of aniline changed this body to a black insoluble gum. The reaction took place equally well with aniline oil or with aniline sulphate. All attempts to purify the product failed. It was insoluble in all solvents except acids, which apparently decomposed it into its original constituents. Reference will later be made to the action of strong nitric acid on the gum. Exactly similar condensations were observed with the following: Ethyl aniline, diethyl aniline, dimethyl aniline, methyl diphenylamine, *m*-chloraniline, *p*-chloraniline, dichloraniline (1–2–4), *m*-nitraniline, *p*-nitraniline, *o*-toluidine, *p*-toluidine, dibrom-*o*-toluidine, *o*-tolidine. Substituted amines which did not give condensations were *o*-nitraniline and dinitraniline (1–3–5). Bright-red products were formed in every case where the amine retained the NH_2 group. With amines in which substitution had taken place in that group brown or black compounds were formed. The reactions of these preparations with fused sodium sulphide is considered under the caption "Sulphur dyes." As in the case of the aniline condensation product, it was not possible to purify these gummy substances. They were decomposed into the original constituents on treatment with strong acids or generally on heating.

REACTIONS OF THE AMINE CONDENSATION PRODUCTS WITH NITROUS ACID.

On the assumption that the condensation products still retain their characteristic amine group, they were treated with nitrous acid in an ice bath, in the hope of obtaining some new bodies through the diazo reaction. In the case of aniline this reaction is—

$$C_6H_5NH_2.HCl + NO_2H = C_6H_5N:NCl + 2H_2O.$$

When this substance alone is heated it decomposes, yielding phenol, but in the presence of other substances, such as some unaltered aniline, reactions of technical importance can be brought about:

$$C_6H_5N:NCl + H_2O = C_6H_5OH + N_2 + HCl,$$

or

$$C_6H_5N:NCl + NH_2C_6H_5 = C_6H_5N:N.NHC_6H_5 + HCl.$$

The product of the latter reaction is diazo-amidobenzene, a starting point for the preparation of an important group of dyes. Application of the diazo reaction to the condensation products above described did not generally result in apparent change. In some experiments an excess of the amine reacted in a manner quite characteristic of the amine itself without any substituted groups. The general inertness of these bodies under such conditions leads to the conclusion that substitution takes place in the amido group of the condensation products. This is further verified by the fact previously shown, that all primary amines gave bright-red condensation products, while the others gave brown or black substances.

REACTIONS WITH NITRIC ACID.

Concentrated nitric acid was found to have a very vigorous action on the dry "lignone" preparation and on the sulphite liquor itself at high temperatures. The organic matter of the dry "lignone" is completely oxidized, chiefly to oxalic acid, in the presence of a sufficient excess of the acid. Nitrous acid fumes are evolved, and the odor of acetic acid can be distinctly detected. The action of nitric acid on the waste liquor is less violent. When a mixture of one part strong acid and ten parts of liquor is warmed, action begins at once. Nitrous and acetic acids are evolved, as with the dry product, and the color of the solution changes from dark brown to bright, golden orange. This solution, after neutralization of the free nitric acid by an excess of sodium acetate, was found to dye wool and silk a beautiful orange-yellow. This yellow dyestuff, which for convenience may be called lignone yellow, is of peculiar interest as a product to be recovered that may be valuable, and it was therefore carefully studied.

LIGNONE YELLOW.

Difficulty was at first experienced in separating the dye from the liquid. Cloth could be dyed directly in the liquid with excellent results, but on evaporation the dye lost a great deal of its coloring power. By evaporating it in partial vacuum to a thick sirup and then reducing it to dryness in a warmed vacuum desiccator, it was finally possible to obtain the desired material in dry form. It is a light-yellow powder, very porous, and extremely hygroscopic, which latter property considerably diminishes its commercial value.

Samples of woolen cloth dyed in baths prepared from the dried material in the proportion of 2 per cent of the dye, by weight, were very beautifully colored. The color is retained on boiling for half an hour in soap solution, dilute acetic acid, or dilute alkali. It withstands the action of bleaching powder, chromate, and other oxidizing agents. It will stand direct summer sunlight for two days without apparent discoloration, but it is affected on the third day; so it is, therefore, only moderately fast to sunlight.

Lignone yellow is exceedingly soluble in water and in ethyl alcohol. On evaporation of these solutions it yields a pasty mass which is completely dried with difficulty. When dried at 100° C., it is decomposed with evolution of nitrous oxide. It can be eventually oxidized with nitric acid to oxalic acid. From the manner of its formation it might be thought to be a nitro-body and in its dyeing properties it resembles picric acid; but it differs from the latter and from other nitrophenols in several particulars. Picric acid, or tri-nitrophenol, crystallizes from hot water and is difficultly soluble in cold water. The same is true of para-nitrophenol. Ortho- and meta-nitrophenols melt at 45° C. and 96° C., respectively. The three dinitrophenols are converted to picric acid on further nitration. If lignone yellow is an aromatic nitro-body, it must be more complex than any of the nitrophenols. Repeated attempts to reduce this dye were made, but no amido-body could be detected after attempted reduction with zinc dust, zinc and hydrochloric acid, iron and sulphuric acid, ammonium sulphide, hydrogen sulphide, or the electric current. In no case did nitrous acid bring about any reaction after these attempts at reduction. Generally, the yellow color was not destroyed. Neither weak chromic acid nor bleaching powder destroy the color. Long-continued boiling of the original sulphite liquor with sodium nitrite gives a liquor with feeble dyeing properties, the color being like that of the nitrated substance. It is possible, therefore, that the dye is a nitroso-compound of some complex radicle rather than a nitro-body. All attempts to prove this point resulted negatively and the question of the fundamental character of the dye remains open.

REACTIONS OF THE AMINE CONDENSATION PRODUCTS WITH NITRIC ACID.

It was thought that the nitration of the substances produced by the condensation of the "lignone" substance with various amines might give rise to dyes of different character, and that the latter might have technical value as well as furnish some clue to the nature of lignone yellow. Accordingly, the different condensations described under "Reactions with aromatic amines" (p. 30) were submitted to the action of dilute nitric acid and the dyeing properties of the resulting solutions were tested on samples of wool. To obtain comparative results, the same quantities of the various components were used each time. As many of the amines are themselves capable of easy nitration under suitable conditions, a blank test was made each time, the amine tested being used without any sulphite liquor. The results of such blank tests as gave a dye in any way similar to that resulting from the condensation product are not recorded as positive. In each test approximately one part of the amine and one part of nitric acid were used with twenty parts of the sulphite liquor. The results of the tests are summarized in the following table:

Nitration of products resulting from the condensation of "lignone" and amines; wool dyed in resulting liquors.

Amine.	Color of dye produced.	Intensity of color.	Color of blank.
Aniline	Golden yellow	Strong	Colorless.
Dimethyl aniline	Dark yellow	Strong	Yellow.
Ethyl aniline	Olive green	Strong	Olive brown.
Diethyl aniline	Greenish yellow	Weak	Colorless.
Methyl diphenylamine	Lemon yellow	Weak	Brown.
m-Chloraniline	Red, washing out yellow	Weak	Pale pink.
p-Chloraniline	Reddish orange	Strong	Colorless.
Dichloraniline	Reddish brown	Strong	Pale orange.
o-Nitraniline	Golden orange	Strong	Colorless.
m-Nitraniline	Golden orange	Strong	Colorless.
p-Nitraniline	Dark orange	Strong	Colorless.
Dinitraniline	Canary yellow	Weak	Colorless.
o-Toluidine	Golden yellow	Strong	Colorless.
p-Toluidine	Dark orange	Strong	Colorless.
Dibrom-*o*-toluidine	Golden orange	Strong	Colorless.
o-Tolidine	Brownish yellow	Strong	Purple.

With the exception of one or two doubtful cases, it appears that the condensation products enter into reaction with nitric acid just as "lignone" alone does, and that the shade and intensity of the dyes produced by the reaction vary from green through orange and yellow to brown, depending on the nature of the amine that is used. Some general observations can also be made from this study. Substitution in the amido group of ethyl aniline, etc., gives greenish shades, and the lighter the substituting groups the more pronounced the green. In mono-substituted aniline, the para-compounds give the most brilliant and powerful dyes, and then in decreasing brilliancy the meta- and the ortho- compounds. The most powerful and brilliant dyes of the series in the table were those produced by *p*-chloraniline, *p*-nitraniline, and *p*-toluidine. Chlor-compounds give the most brilliant dyes; the nitro-compounds give dyes of more strength and body. As with the nitrated "lignone" alone, here also every attempt failed to produce amines from their nitrated substances. Many of the products, it is true, gave a reaction with nitrous acid after reduction, but in all such cases the reaction was that of the amine originally used and the resulting substances could be prepared equally well without the addition of "lignone." Reduction of the nitraniline products was not attempted, as too great complication would arise from the presence of the nitro-groups known to be present.

SULPHUR DYES.

Many organic substances yield dyes when fused with a mixture of sulphur and sodium sulphide. These so-called sulphur dyes are now manufactured in a variety of colors. They are direct cotton dyes—that is, they dye cotton without the aid of a mordant—and they are very fast. Their cheapness and valuable properties have caused them to come into wide use. An attempt was made to prepare dyes of this kind from sulphite waste liquor and from several of its condensation products. In particular, it was hoped to obtain dyes of bright color, red or blue, because such colors are especially desirable and bring good prices on the market. Brown and black are much more readily made, and are consequently cheaper. Mixtures of one part dry crude "lignone" and one-half part each of sodium sulphide and sulphur were fused for fifteen minutes at a low heat. The resulting mass was extracted in hot water and the extract filtered and evaporated. From 25 grams of dry "lignone" there were made 20 grams of a green powder, soluble in water containing a little sodium sulphide. This powder was found to be a true sulphur dye, coloring cotton a dark green, which changed to a good black on oxidation in the air or on subsequent treatment in a chrome bath. Compared with commercial dyes in the market, this dye is worth about 7 cents a pound in its impure condition. About half its weight is inert material, which can be removed by proper treatment. Similar experiments in preparing sulphur dyes were made with the condensation products previously mentioned. (See p. 33.) The shades of the resulting dyes were somewhat modified by the presence of the amine, but they were all browns, grays, or black. No advantage was apparent in the use of the condensed products over that of the untreated "lignone."

COMMERCIAL POSSIBILITIES OF LIGNONE DYES.

Two of the best dyes, namely, those resulting from the nitration of "lignone" alone and of "lignone" condensed with *p*-chloraniline, were prepared in large quantity, in order to determine the yield and the cost of the process. One hundred grams of dry crude "lignone" were treated with 50 cubic centimeters of concentrated nitric acid (specific gravity 1.42), and the resulting solution evaporated in vacuo. Seventy grams of lignone yellow were obtained. Compared with mandarin yellow, the technical dye approaching it most nearly in color and fastness, it is worth 18 cents a pound. The cost of nitric acid would be 5 cents a pound of dye. To neglect for the moment the cost of evaporating the original liquor, the margin between the cost of the acid and the value of the dye appears to be sufficient to pay for the work of handling. This would be true at places where expediency makes it necessary to evaporate the liquor in any case, and also at places where the dye could be used in liquid form as made. The cost of evaporating the liquor, however, would undoubtedly be greater than the value of the dye. It must also be borne in mind that there is necessarily a limited market for a dye of this kind—a market too limited, in fact, to permit any general adoption of this plan of utilization, even if it were very much cheaper. A similar test of the cost, yield, and value of the dye from *p*-chloraniline gave an additional cost of 9 cents a pound of dye for aniline, making the total cost for material 14 cents a pound. While the color was much more brilliant, its red shade lowers slightly its market value, pure yellows and greenish yellows being in much greater demand for use than browns. As an additional market outlet, however, this dye may possibly help in the utilization of sulphite waste liquor. The actual results attained in this investigation are not considered so important as the fact that a new and interesting series of reactions of "lignone" have been discovered. Further development of these dyes is the work of the skilled expert in textile coloring. It is not too much to expect that such an expert, possessing full knowledge of the technique of dyeing, will be able not only to simplify and to reduce to a practical working basis the methods herein outlined, but also to discover new and more valuable products by further experimentation along similar lines.

CONCLUSION.

The foregoing study of sulphite pulp waste liquor and of the possible utilization of the organic material in it may be summarized in a few sentences.

Stream pollution by the waste from sulphite pulp mills is extensive and wasteful; every year over two and a half billion pounds of solid matter from this source are turned into the rivers and lakes of the United States.

The problem of utilizing this immense amount of waste matter has been studied for a long time, and numerous processes for using or for destroying it have been devised, but they are all unsuccessful, either because there is only a limited market for the proposed product or because the suggested process is prohibitively costly.

Successful disposal of the sulphite waste liquor lies obviously in the utilization of the so-called "lignone" in it, but aside from the employment of this substance to a slight extent as an adhesive and as a source of tannin, no practicable way for its direct use has been devised.

The waste consists principally of wood material separated from the wood fiber by the action of a strong sulphite solution on wood chips; it is a compound of "lignone" with sulphur; but the exact nature of the union has not been definitely demonstrated.

Experimental evidence indicates that the sulphur-bearing compound in the waste liquor is not a true sulphonic acid; at all events, it does not react like an ordinary sulphonic acid. Its condensation with the aromatic amines point to its probable aldehydic nature.

Nitration of "lignone" and of its amine condensation products gives a series of dyes the shade and intensity of which vary from green through orange and yellow to brown, depending on the nature of the amine that is used. These substances dye wool directly, giving brilliant colors that are fast to soap, acids, and alkalies, and reasonably fast to sunlight. One of them, named lignone yellow, and made by nitrating crude "lignone" itself, dyes wool and silk a beautiful orange yellow. Fusion of "lignone" with sodium sulphide and crude sulphur produces a sulphur dye that colors cotton dark green, changing to black on treatment in a chrome bath.

A search for new compounds, such as that made in the present investigation, possesses the serious drawback that much time and effort may be spent without tangible results; on the other hand, an important discovery may be made at any time. Certain reactions brought to light in this work with "lignone" reveal great possibilities. Though the dye called lignone yellow has only slight commercial possibilities and is at best but a partial solution of the major problem, yet the opportunities for further progress along this line are pregnant with the ever-present chance of discovering valuable substances. The number of "lignone" condensation products is almost unlimited, and a wide field for investigation is thereby offered. Only a small portion of a large and interesting territory has been covered by these experiments and the results are by no means conclusive. But it is hoped and expected that the mere reopening of this old and practically abandoned problem by calling attention to these new lines of attack may result in renewed investigation and in the ultimate utilization of a substance that to-day is probably the most valuable waste material known to industrial chemistry.

SURVEY PUBLICATIONS ON STREAM POLLUTION.

The following water-supply papers of the Survey discuss stream pollution. Nos. 103, 152, 185, and 194 can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at the prices stated. Any of the others will be sent free, while the edition lasts, on application to the Director of the United States Geological Survey.

72. Sewage pollution in the metropolitan area near New York City and its effect on inland water resources, by M. O. Leighton. 1902. 75 pp., 8 pls.
79. Normal and polluted water in northeastern United States, by M. O. Leighton. 1903. 192 pp.
103. A review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp. 10c. (See No. 152.)
108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.
113. The disposal of strawboard and oil-well wastes, by R. L. Sackett and Isaiah Bowman. 1905. 52 pp., 4 pls.
121. Preliminary report on the pollution of Lake Champlain, by M. O. Leighton. 1905. 119 pp., 13 pls.
144. The normal distribution of chlorine in the natural waters of New York and New England, by D. D. Jackson. 1905. 31 pp., 5 pls.
152. A review of the laws forbidding pollution of inland waters in the United States (second edition), by E. B. Goodell. 1905. 149 pp. 10c.
179. Prevention of stream pollution by distillery refuse, by Herman Stabler. 1906. 34 pp., 1 pl.
185. Investigations on the purification of Boston sewage, by C.-E. A. Winslow and E. B. Phelps. 1906. 163 pp. 25c.
186. Stream pollution by acid-iron wastes, a report based on investigations made at Shelby, Ohio, by Herman Stabler. 1906. 36 pp., 1 pl.
189. The prevention of stream pollution by strawboard waste, by Earle B. Phelps. 1906. 29 pp., 2 pls.
192. The Potomac River basin—geographic history; rainfall and stream flow; pollution, typhoid fever, and character of water; relation of soils and forest cover to quality and quantity of surface water; effect of industrial wastes on fishes; by Bailey Willis, R. H. Bolster, H. N. Parker, W. W. Ashe, and M. C. Marsh. 1907. 364 pp., 10 pls.
193. The quality of surface waters in Minnesota, by R. B. Dole and F. F. Wesbrook. 1907. 171 pp., 7 pls.
194. Pollution of Illinois and Mississippi rivers by Chicago sewage; a digest of testimony in the case of the State of Missouri *v.* the State of Illinois and the Sanitary District of Chicago, by M. O. Leighton. 1907. 369 pp., 2 pls. 40c.

O

CORROSION OF WATER PIPES

By EARLE B. PHELPS

Report made to the Sanitary Committee of the National Association of the Master Plumbers of the United States, and reprinted from the Report of the Sanitary Committee for 1907-1908-1909

Mr. David Craig,
National Ass'n. Master Plumbers,
Boston, Mass.

Sir:

I beg to submit the following report upon my investigation into the question of the corrosion of water pipes in certain cities of the Middle West. The investigation was undertaken at your request, the following specific questions being presented:

(1). What is the cause of the corrosion noted? In particular does it result from the chemical treatment of the waters?

(2). What is the sanitary significance of the deposits observed in the pipes?

(3). What remedies can be adopted?

The difficulties were stated to be of common occurrence in cities where chemicals are used in treating the water and most especially marked in St. Louis, Mo. Samples of various kinds of pipe which had been in service at St. Louis for various lengths of time were forwarded me, together with an account of the method of water purification in use there and analyses of the water before and after treatment.

The three questions raised will be discussed in the order in which they are given with special reference to the problem at St. Louis.

The Nature and Cause of the Corrosion.

The specimens of pipe submitted were carefully examined with the following results: The action in question is chiefly noticeable in galvanized iron pipes. Specimens of such pipe which had been in service for but a few years were almost completely choked with a yellowish white substance closely adherent to the surface. It was removed only with difficulty and then brought away with it flakes of the zinc coating of the pipe. The latter was evidently much corroded as indicated by the way it flaked off. Specimens of black iron boiler tubing in service for many years showed much less of the deposit and in fact no more than would have been expected when the character of the water is taken into consideration. This deposit was the characteristic hard scale usually formed in boiler tubes when hard waters are in use. Specimens of brass pipe showed no deposit whatever, being apparently as good as new. These facts lead to the belief that the material is not a mere deposition which might occur normally when hard waters are used, but that it resulted directly from the action of the water upon the zinc coating of the pipe. Analysis of the material confirmed this view. It was found to contain over 80 per cent, of pure zinc oxide, with a small amount of carbonate, some silica and a very little carbonate of calcium. The analysis follows:

ANALYSIS OF MATERIAL FROM GALVANIZED IRON PIPE

Oxide of Zinc - -	**80.4%**
Oxide of Calcium - -	**2.1**
Oxide of Iron and Aluminum	**4.0**
Carbonic Acid as Carbonate	**3.2**
Silica and Insoluble matter	**9.8**
	99.5

Such a result can have but one interpretation. The water has a very corrosive action upon zinc, first dissolving it slightly, at the same time oxidizing and precipitating it as an hydrated oxide. Some slight combination with the carbonate of the water then takes place by which an insoluble basic carbonate is formed; at the same time some of the minor constituents of the water are deposited, particularly oxide of iron and aluminum which assist in cementing together the slowly forming zinc compound into a hard concretion.

It is therefore of special importance to determine if possible what constituents of the water are especially responsible for this solvent action. Added interest is given to this point by the assertion that no such results were noticed before the introduction of the present method of treatment. This statement ought not of course to go unchallenged in such an inquiry as this and the writer has been at considerable pains to verify it. The fact is disclosed that in many other places similar difficulties have followed the introduction of water purification systems using coagulants. It is well known, of course, that alum would exert such a corrosive action but in the present case sulphate of iron, and not alum, is used as the coagulant and in general, in any properly operated plant, undecomposed alum never finds its way to the water main. Such a result could only result from mismanagement of the plant and ignorance of the process. The same remarks apply equally to iron sulphate with the additional well-known fact that the iron compound would not in any case directly give rise to the action noted.

Careful study of the analyses submitted throws no light upon the question. These figures are included here as a matter of record. The chemical treatment involves the addition of iron sulphate, commonly called copperas or green vitriol and of lime. The slight excess of lime serves to precipitate the iron which separates out in small flocs. This floculent precipitate settles rapidly, carrying with it most of the suspended clay and the bacteria and much of the color. The lime further acts upon the bicarbonate of calcium and the magnesium salts already in the water, removing them in part. The chemical reaction between the copperas and the carbonates of the water results in an interchange of acid radicals, the carbonate radical being precipitated with the iron and the sulphate radical of the copperas remaining in solution with the calcium. The end result from the chemical standpoint therefore is the removal of part of the calcium and magnesium and of the carbonate radical and the addition of some sulphate radical. The changes brought about by the purification will be clear from the following analyses of the water before and after treatment and the amount of each constituent removed or added:

ANALYSIS OF THE MISSISSIPPI RIVER WATER BEFORE AND AFTER PURIFICATION

(Parts per million)

	Before	After	Removed
Calcium - - -	34.2	19.1	15.1
Magnesium - - -	11.6	5.6	6.0
Sodium - - -	19.7	19.7	0.0
Carbonate radical - -	153.6	52.5	101.1
Sulphate radical - -	38.5	59.6	21.1 (addl)
Chlorine - - -	8.0	8.0	0.0
Total	265.6	164.5	101.L

The fact that the zinc alone was attacked suggests the possibility of electrolytic action. The principles underlying these phenomena may be thus stated. If into a dilute salt solution a strip of zinc and one of copper or brass be dipped, and an electric connection be made between their outer ends, a current will flow whose intensity is dependent upon the electrolytic character of the solution. Such a current flows always from the zinc through the water to the copper and its passage constantly dissolves the zinc. Now in any household water pipe system with brass faucets and particularly brass hot water pipes we have just such an arrangement, an electric battery if you will, in which only the zinc pipes are affected and which effect is determined entirely by the character of the water. We have but little exact knowledge of the amount of action to be obtained from any given combination of dissolved substances, too little in fact to enable us to determine in advance just what the action would be in any given case. A simple experiment, however, furnishes the necessary proof that the treated water of St. Louis under these conditions is much more corrosive than the utnreated. For this purpose waters were carefully prepared to duplicate exactly the analyses already given. With each of these waters a small battery was made up as follows: Two glass test tubes were filled with the same water. Into one was placed a strip of zinc and into the other, one of brass. The ends of these strips were connected and the circuit was completed by a piece of platinum wire running from one tube to the other. The two little batteries were then kept under constant observation. Within three days the zinc in the treated water battery was being noticably attacked and the water was rendered turbid by the basic zinc carbonate which was formed. No action was visible on the zinc exposed to the untreated water during the entire time of observation, over two weeks. Of course this experiment was arranged to obtain the maximum effect in a short time. In practice the circuits are not so short and the current is not so strong. The experiment demonstrated conclusively, however, that the altered electrolytic character of the water is the cause of its increased corrosive action.

One other point is worthy of attention here. It is well known that what are called colloidal substances, of which the ordinary coloring matter of water is an example, have the power to neutralize certain electrolytic properties of dissolved salts. In such cases the colloid is generally precipitated. The experiment cited above was repeated after a little coloring matter obtained by steeping some dead leaves had been added to the water. The zinc plate then became slightly tarnished by a dark deposit and was thenceforth protected from the electrolytic action so that its solution was very much, though not entirely, prevented.

Evidently therefore the removal of the coloring matter from the water has also contributed to the undesirable result. To sum up then, this water acts upon galvanized pipes electrolytically, in those places where galvanized and brass pipes are placed in the same system. This action is more severe in the case of the purified water than it would be with the raw river water, owing both to a change in the mineral character of the water and to the removal of the protective effect of the colloidal coloring matter.

Sanitary Significance.

From a sanitary standpoint the action described may be considered quite harmless. The compound of zinc formed is quite hard and not readily removed. In any case only minute traces of zinc are actually oxidized in any short time and the salts of zinc are not among the poisonous metal salts like copper and lead. Oxide of zinc is used in healing ointments for application to raw burns and for treatment of skin diseases. In my opinion no possible danger to the public health exists in this case. The sanitary danger lies all on the side of the untreated water.

Remedies.

Two courses of action suggest themselves, as possible remedies. Obviously galvanized pipes are not suited for use with this water in connection with brass faucets and other brass fittings. Either all brass work must be removed, a very serious matter, or some substitute for the galvanized pipe must be found. There would seem to be no alteration possible in the method of treatment at the purification works which would do away with the difficulty. Judging from the chemical analyses it would not appear that this water would have any solvent action upon lead, certainly not upon lead which had been in service a short time. This statement is strictly local, and not of general,, application. For the case in question I suggest a substitution of lead for galvanized iron pipe; as an additional safeguard the solvent action of the water upon lead pipe should be carefully determined by a competent chemist.

In conclusion the results of this study may be summed up as follows:

The waters of the Mississippi River after purification at the water works of St. Louis, are exceedingly corrosive for galvanized iron pipe. This corrosive action has been more noticeable since the introduction of the present system of purification by means of iron sulphate and lime. Similar treatments of waters elsewhere, where either sulphate of iron or sulphate of alumina, (alum), are used, have in many cases resulted in increasing the corrosive action of those waters.

The only essential change in the chemical character of the water in question due to treatment, is the removal of a large portion of the carbonate ions and the substitution of sulphate ions in their place. Chemically considered, the water is not rendered more corrosive for zinc by this change.

In the presence of electrolytic action, however, sulphate ions tend to attack and dissolve the zinc, while carbonate ions protect it.

Very weak electrolytic action is always present when dissimilar metals are in contact with each other and both in contact with a solution containing such salts as are found in this water. Such action is particularly noticeable when the metals are zinc and copper or zinc and brass. Where copper or brass fittings or hot water pipes are employed in the neighborhood of galvanized iron pipes the water in question is bound to set up electrolytic action with the consequent corrosion of the zinc.

No sanitary question is here involved.

The remedy in the particular case of St. Louis lies in the substitution of lead pipe for the galvanized iron pipe now employed. Tin lined or other protected pipes may serve equally well. The water will not have any serious solvent action upon the lead if the specimen analyses submitted are representative. Before making any radical changes, however, this point should be more carefully studied.

As regards other waters of this kind no general statements can be made. Where increased solvent action has followed the introduction of chemical purification processes the cause is probably the same as that assigned in this case. In some cases, however, the substitution of lead pipe might give rise to more serious evils, and the proper remedy can only be determined after a careful study of each individual case.

Respectfully submitted,
EARLE B. PHELPS,
Sanitary Expert.

Boston, Mass., May 25, 1908.

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SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

AN INVESTIGATION OF THE SANITARY CONDITION OF THE GOWANUS CANAL, BROOKLYN, NEW YORK

BY CHARLES F. BREITZKE

INTRODUCTION

THE following is an abstract of a part of the thesis submitted in May, 1906, by Norman P. Gerhard and the writer, at that time candidates for the Degree of Bachelor of Science at the Massachusetts Institute of Technology.

The object in view in the preparation of the original thesis on file in the Engineering Library at the Institute was to investigate the condition of the Gowanus Canal, Brooklyn, New York, and to suggest a plan for remedying the nuisance. The sanitary investigation was made by the writer. The discussion of the methods which might be applied to remedy the conditions was written by N. P. Gerhard. In view of the fact that the problem has also been considered by the Brooklyn engineers and that a flushing tunnel is now under construction, it was thought best in the publication of this abstract to omit N. P. Gerhard's part of this study.

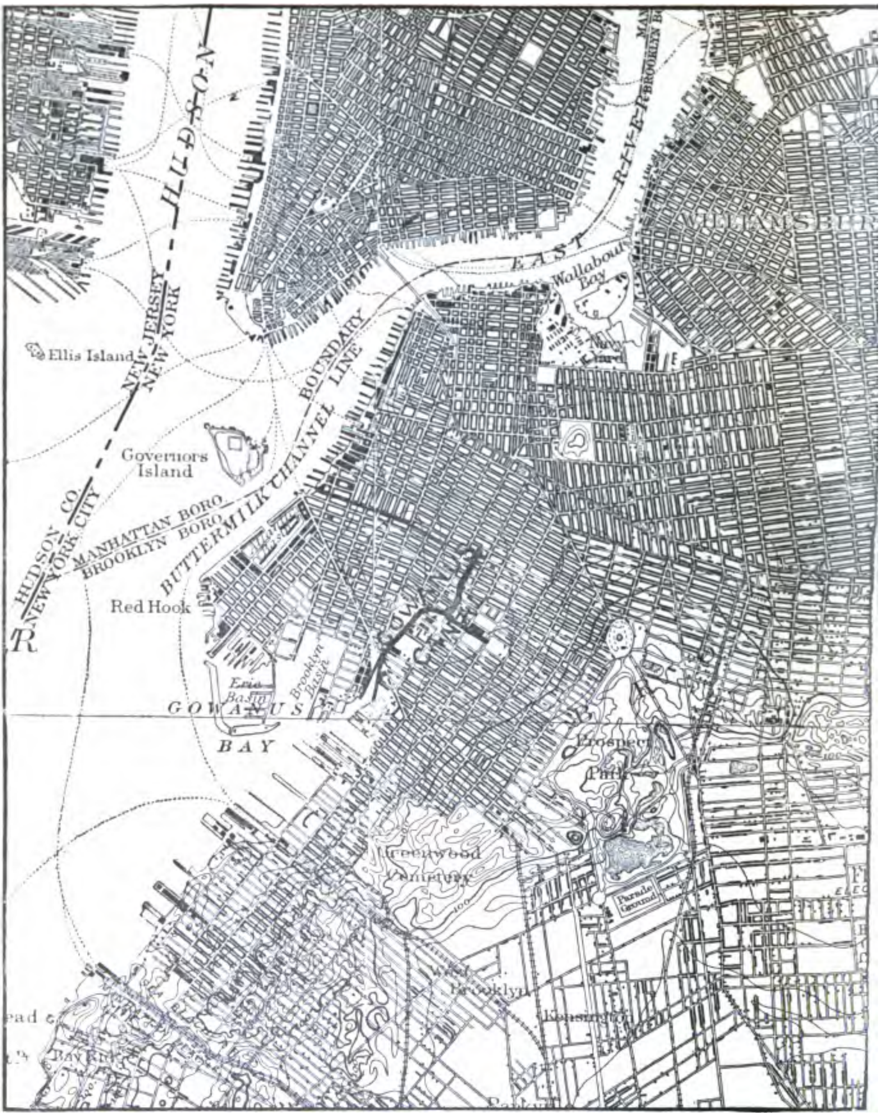

Fig. 1.—Map of a Portion of New York Harbor Showing the Location of the Gowanus Canal

General Description

Location.—The Gowanus Canal is located in the western part of the Borough of Brooklyn, City of New York, midway between Prospect

Park and Upper New York Bay. The canal is closed at its upper end and opens at the lower end into Gowanus Bay, a part of New York Harbor. Its position is best seen by a study of the appended United States Geological Survey map (Fig. 1).

Construction and Data. — Originally this portion of Brooklyn contained a stream known as Gowanus Creek. Its shores were everywhere surrounded by great salt marshes formed by the combined action of the tide and the wash from the surrounding upland. This inlet was then navigable at all stages of the tide. Since that time the marshes have been entirely filled in, mainly from gravel knolls which were cut down in the western part of the city. The original shore line in 1776 and the present outline of the canal are shown on the accompanying map (Fig. 2). A glance at the topographical map shows that the land slopes down towards the canal on the north, east, and west; while on the south it is flat, this being made land. For the length of a block on either side of the canal the ground is practically level.

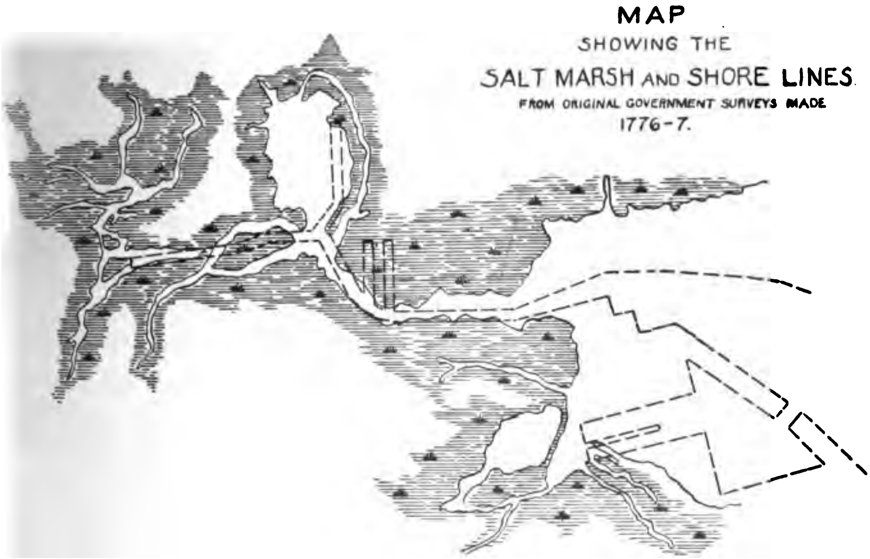
MAP
SHOWING THE
SALT MARSH AND SHORE LINES
FROM ORIGINAL GOVERNMENT SURVEYS MADE
1776-7.

FIG. 2.

The act authorizing the construction of the canal was passed in 1849. The original cost of construction was $452,131, and this was assessed on the portion of the city benefited. The lateral basins provided for were to be built by private enterprise. The date of completion was about 1860.

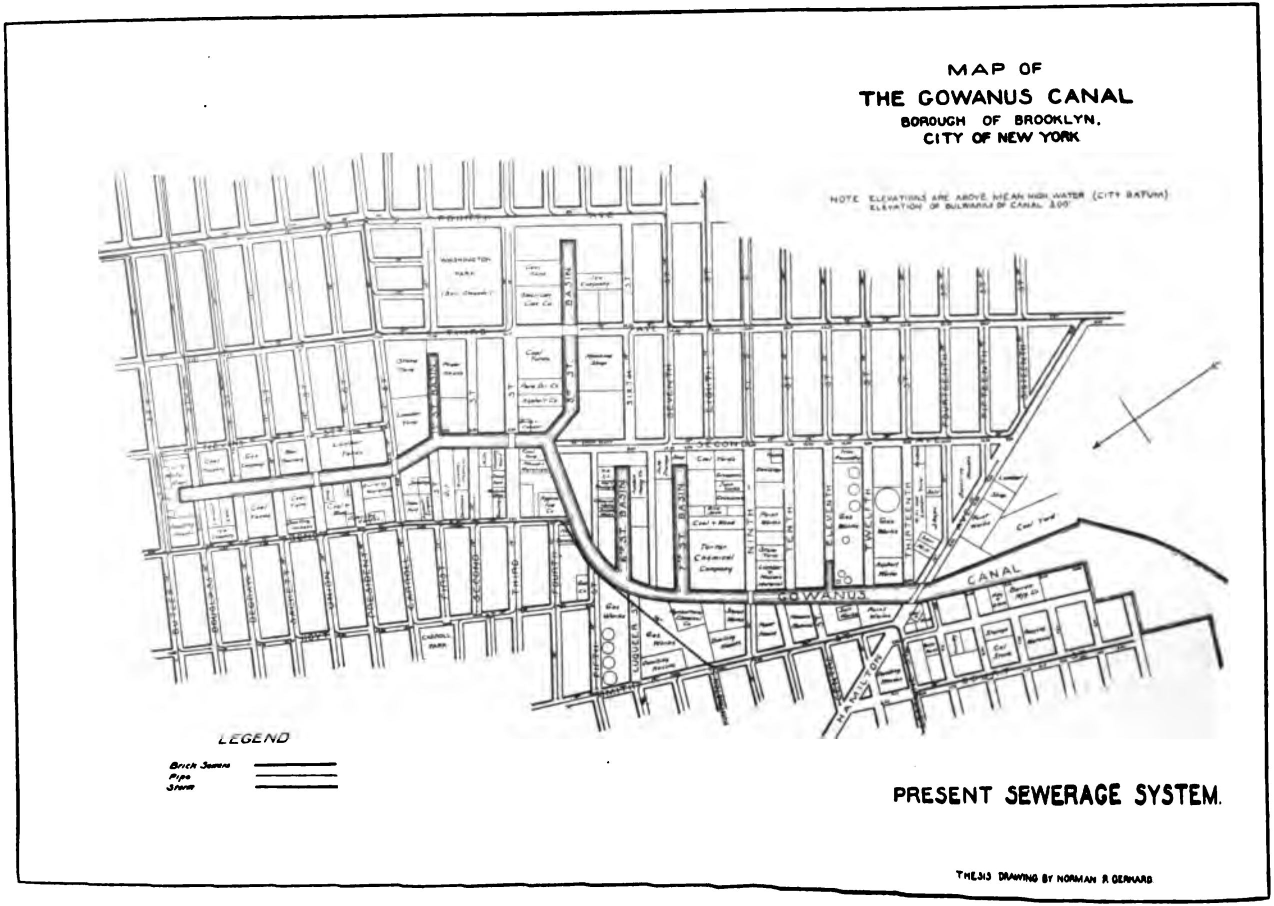

Fig. Scale: 1200 Feet = One Inch

The canal (Fig. 3) was constructed with two objects in view. One was to drain this section of the city, including an area of about 1,700 acres, chiefly marshes, and to make it fit for agricultural use and building purposes. The other object was to make a navigable waterway for all river and coasting craft, such as sloops and schooners of light draft, towboats, and barges.

The length of the main canal is about 6,575 feet, and the lateral basins are approximately 3,600 feet in length. The total length is, therefore, about 10,175 feet, or somewhat less than two miles. The legal width of the canal is 100 feet. Its average depth is 10 feet below mean low water, but the variations in depth are considerable. At the head it is about 5 feet deep and it grows gradually deeper as Hamilton Avenue is approached. The total capacity of the canal at mean low water is approximately 10,000,000 cubic feet.

Nature of the Locality. — The locality is chiefly a commercial one and consists largely of factories and yards. Certain portions toward the lower end and on the eastern side are not yet built up, and there remain numerous empty lots. The factories and yards extend the entire length of the canal and for the distance of a block on either side. These include gas works, factories, chemical works, ice plants, salt works, oil refineries, asphalt and paving material plants, building material yards, coal and wood yards, power houses, machine shops and foundries, storage warehouses, junk yards, and city dumps.

Immediately adjoining this business section on either side of the canal is a thickly populated tenement district. Gradually, as the distance from the canal increases, more and more houses are found, and the better residence sections are within five blocks on either side.

The photographs accompanying this article (Figs. 4 to 7) give a general idea of the nature of the locality.

Value of the Property. — The assessed value of the land fronting the canal is $3,315,000. The canal enables the abutters easily to obtain supplies of coal, brick, lumber, oil, etc., from schooners and canal boats towed up the canal by tugs. An examination of records on the amount of traffic on the Gowanus Canal showed that during a recent year 26,680 vessels passed Hamilton Avenue, an average of eighty-seven per day. At Ninth Street, Third Street, and Union Street, the average per day was eighty, forty-eight, and twenty-four vessels, respectively. There is no railroad in this part of the city, and the canal is therefore a great convenience.

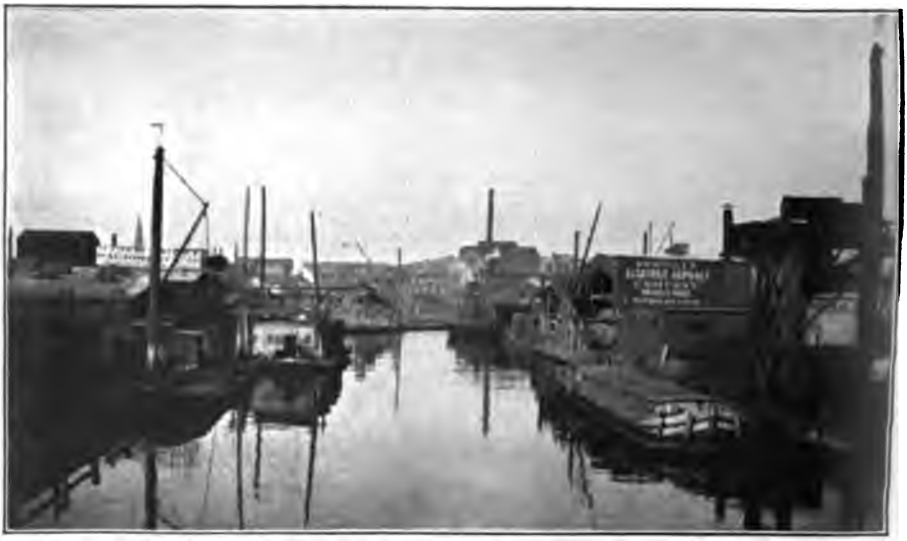

FIG. 4.—FIFTH STREET LATERAL BASIN

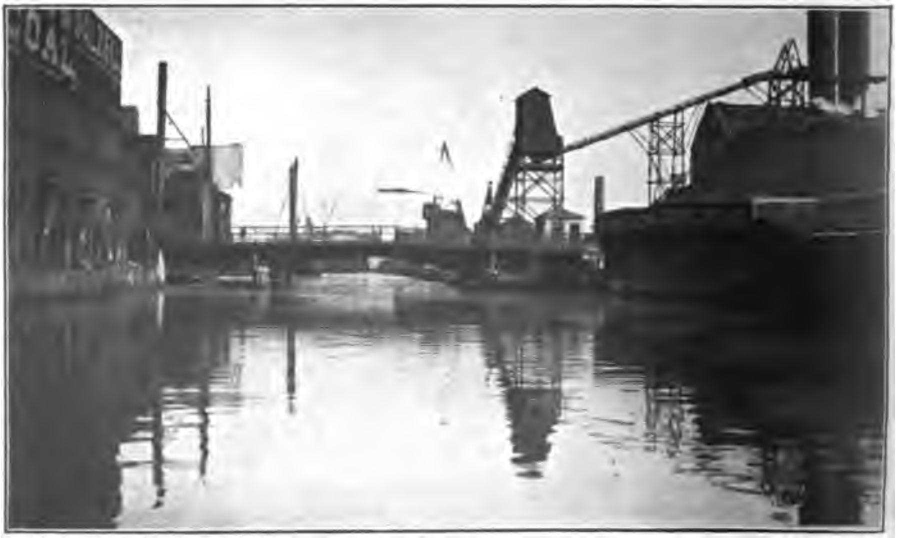

FIG. 5.—CARROLL STREET BRIDGE

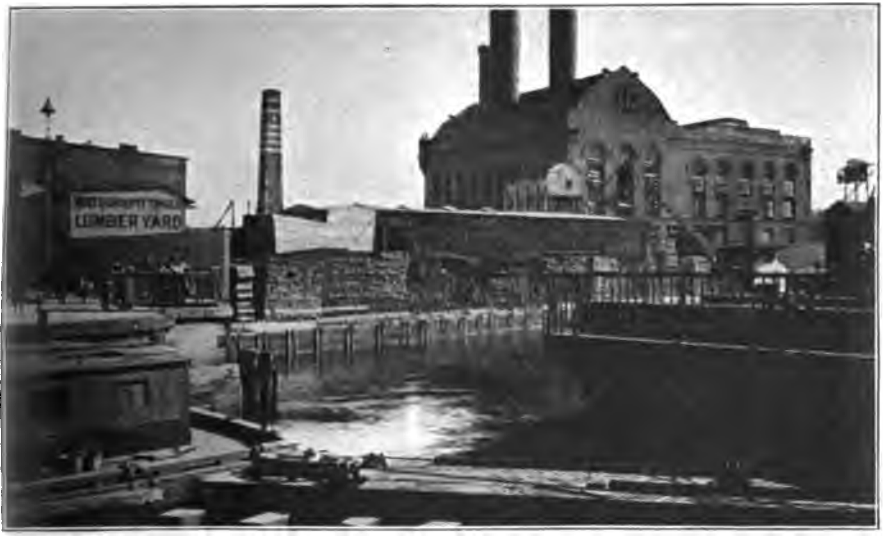

Fig. 6.—View Looking South from Union Street Bridge

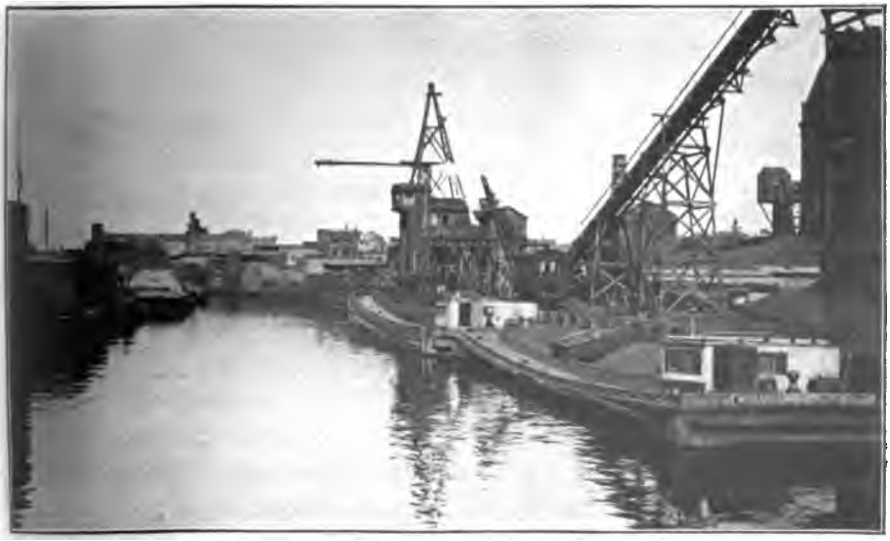

Fig. 7.—view Looking North from Carroll Street Bridge

Tributary Sewers.—With the single exception of Chicago, Brooklyn was the first city in this country to undertake a complete system of sewerage. Therefore when the sewerage system was planned the designing engineer was dependent upon English experience for data in regard to the amount of sewage to be provided for, as well as for the amount of rainfall from any given storm which reaches a sewer within a given time.

The sizes of sewers were determined mainly by the extremes of rainfall, the household sewage being a very small item in comparison. The sewerage was installed in the early sixties. Brooklyn grew very rapidly. Consequently by 1888 the sewers became too small, and the legislature of that year passed an act permitting the discharge of storm water sewers into the Gowanus Canal. In 1892 a 15-foot main relief sewer, which intercepts all the storm water in the mains draining that portion of Brooklyn lying south of Greene Avenue, was brought down to the head of the Gowanus Canal, at Butler Street (Fig. 8), and completed. Nothing but storm water was intended to enter this relief sewer, but, whether by accident or design, it is now flowing during dry weather and is discharging sewage into the canal.

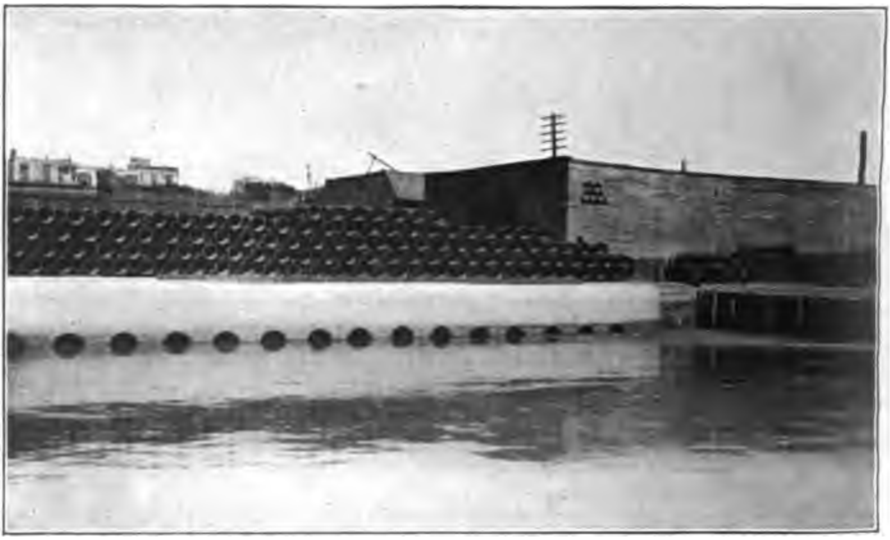

FIG. 8.—OUTLET OF SILT BASIN AT HEAD OF CANAL

In addition, the following storm overflows have also been constructed: 78-inch overflow from Nevins Street at the head of the canal; 60-inch overflow from Bond Street at the head of the canal; 42-inch storm sewer on Douglass Street; 90-inch storm sewer on Degraw Street discharging through a silt basin; 78-inch overflow from Third Avenue main sewer discharging at Second Avenue; 72-inch overflow from Bond Street main sewer discharging at foot of Bond Street.

All of these sewers bring down more or less diluted sewage and street washings during times of storm. The contents of the canal are of the vilest sort. Practically all the industrial plants on the streets adjoining the canal discharge directly into it. The following sanitary sewers empty into the canal: 18-inch sewer on Sackett Street; 18-inch sewer on President Street; 12-inch sewer on Carroll Street; 12-inch sewer on Ninth Street; 12-inch sewer on Hamilton Avenue; 48-inch sewer on Grinnell Street.

With the above exceptions, the streets which terminate at the canal have been left unsewered. The reason given is that there was not sufficient grade to drain the sewers into the mains in the streets running parallel and on either side of the canal.

Current and Deposits.—The canal is always filling up and a constant expenditure of money is required for dredging. The importance of this factor is shown by the following figures on the cost of dredging taken from various reports:

1875	550 feet west and 500 feet east of Bond Street .	$2,500.00
	At Third Street bridge	250.00
1876	No dredging.	
1877	Gowanus Canal	325.00
1878	Gowanus Canal at various bridges	1,995.00
	Gowanus Canal at Sackett Street	130.00
1879	Gowanus Canal at various bridges	1,995.00
	Gowanus Canal at various localities	513.00
1880	Gowanus Canal	1,019.70
1881–1884	No records.	
1885	From Douglass Street (7 feet at low water) to Hamilton Avenue (12 feet at low water) . . .	16,450.00
1886–1893	No records.	
1894	From Butler Street to Union Street . . .	2,980.00
1895	Entire length and width	7,527.00
	Soundings	37.75
1896	Dredging Gowanus Canal	990.00

1897–1901	No reports available.	
1902	Dredging	$5,051 00
	Engineering expenses	106.25
	Inspection	222.50
	Total of all available records	$42,092.20

At present barges at the upper end of the canal are aground at low tide. The depth of the canal is now inadequate for the passage of fireboats.

The mere rise and fall of the tide have apparently no purifying effect whatever, and do not prevent the filling up of the canal with the heavier portions of the sewage. Only after heavy rainstorms, when a large amount of water is discharged from the storm sewers, is there any current noticeable.

Appearance and Odors.—The surface of the water in the canal is covered with a layer of oil, coal dust, and scum. Gases are constantly seen bubbling up through the water, especially at the upper end of the canal. In the summer time the stench at the canal is unbearable, and it is noticed at all times a block away. On certain days not only the immediate locality, but also large sections of the city on the north, west, and east, according to the direction of the wind, are seriously affected. The section on the west was formerly a handsome residence district, but in part owing to this annoyance property has steadily declined in value in the past twenty-five years.

INVESTIGATION OF THE SANITARY CONDITIONS

This investigation was undertaken to learn as much as practicable within a limited time regarding the character of the water now filling the Gowanus Canal and the nature of the pollution now entering it.

In a general way all this work has been undertaken to answer as clearly as possible the following questions:

1. Are all the odors due to the canal or are they due to manufacturing plants along the sides?

2. What is the character of the water which now fills the canal? What is the amount of organic matter present and the amount of oxygen necessary to destroy it? Are there any chemical wastes which inhibit the reduction or oxidation of putrescible substances? What is the amount of those substances which appear to be indifferent to chem-

ical changes, but which silt up the canal? How does the canal water compare with unpolluted sea water? How does it compare with the water in that part of the harbor adjoining its outlet?

3. What is the character of the entering pollution from the factories? Which is the larger factor in bringing about pollution, industrial wastes or sewage?

4. Do the ebb and flow of the tide renew the water in the canal, or does much of this water flow back and forth?

5. Is the water continually active in digesting or oxidizing and capable of rendering innocuous the pollution that comes into it?

6. What is the proportion of sewage, fresh water, and salt water in the canal; that is, what is the sewage density or the quantity of sewage per cubic foot of water?

7. What quantity of East River water would be required to dilute sufficiently the daily discharge? What quantity will be required to flush out the present contents of the canal if dredging is first resorted to?

This report will be divided into five parts:

1. The sanitary inspection.
2. Chemical and bacteriological analyses, with their interpretation.
3. Summary of existing conditions.
4. Recommendations, with calculation of the water to be pumped.
5. Summary and conclusions.

THE SANITARY INSPECTION

As careful an inspection as the time would permit was made, especial attention being paid to the incoming sewers and resulting conditions. The canal in its present state is exceedingly obnoxious, the stench even in the winter time being very disagreeable. The water is black, warm, and foul. No fish have been caught in the canal for many years. There is practically no current. The appearance of the surface and bulwarks is disgusting, especially near the sewer outlets.

The surface of the canal is covered with scum. In the upper portion (Fig. 9) this is characteristic of domestic sewage, such as grease and slime, partially disintegrated human fæces, and other organic matter. The lower portion of the canal from the Bond Street sewer outlet to Gowanus Bay is covered with unsightly patches of floating rubbish which have been accumulated by the action of the tugboats, wind, and tide. These patches consist largely of brown and yellow oily substances, which spread out in thick layers on the water surface and seem to gather up all the other floating *débris*, such as waste paper, fecal matter, melon rinds, banana skins, kitchen refuse, tin cans, broken boxes, coal dust, and other matter.

The water throughout the canal is exceedingly turbid, especially at the upper end. The turbidity is so great that the water is of a light gray color. The color becomes darker, however, and the turbidity less as the outlet is neared. In no place in the canal is it possible to see the oar blades when in a rowboat.

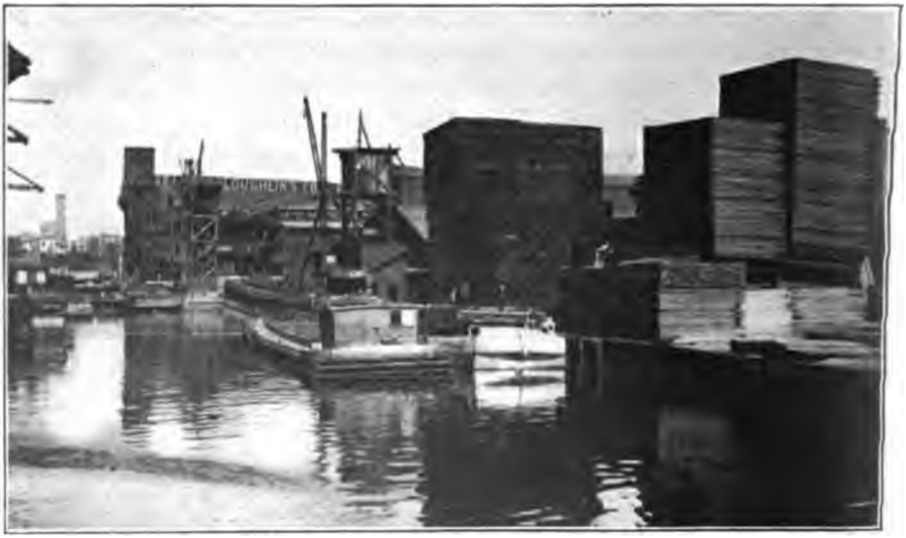

FIG. 9.—VIEW LOOKING NORTH FROM UNION STREET BRIDGE SHOWING LAYER OF SCUM IN THE FOREGROUND

Practically all the plants along the canal discharge directly into it, but the amount of sewage from these is small when compared with that contributed by the city sewers. Not only is the discharge of the sewers greater than that of the factories, but its amount and its offensive character are shown by the bad condition of that part of the canal into which it discharges. These sewers have all been named in the first part of this report. All the so-called "storm sewers" in dry weather discharge concentrated sewage, as the chemical analyses will show. The chief offender, however, is the 15-foot relief sewer at the head of the canal. During the quieter hours of the day the depth of the dry weather flow in this sewer is about 6 inches. This is continually bringing down waste paper, hair, and other sewage stuff. White scum covers the water surface in front of its outlet. Slaughterhouses drain into this sewer, for at times large quantities of blood are discharged. On wash days suds are in abundance.

A large silt basin was provided at the head of the canal to settle out the solid matter and detritus carried down in the storm sewers during heavy rains. A photograph of the silt basin is shown in Figure 8. The settling basin, however, intercepts only the coarse, heavy material. The finer material passes through and silts up the canal. In October the canal was dredged from Union Street to the head end. By February the deposit in front of the outlets filled up this section of the canal to approximately 5 feet below mean low water. In April the top of this bank was only about 3 feet below. The conditions are such that at low tide all the canal boats are aground in this portion of the canal.

The continuous discharge of the Bond Street sewer was easily detected by means of the brown and yellow oily substance already referred to. This sewer has two 36-inch outlets.

Among the more conspicuous of the private sewers are those of the gas works, which continually discharge a yellow-brown liquor. There are several of these gas plants. Their discharge outlets are from 8 inches to 12 inches in diameter and discharge full. It is to this, doubtless, that the tarry incrustation of the posts and bulwarks of the canal is due.

Much hot water is discharged into the canal. In cold weather this causes a heavy fog to hang over it. The large amount of vapor given off and the constant bubbling up of gases make the canal look boiling hot. In February the temperature of the water was 65° F. at the head of the canal. This gradually became higher on going down the canal, until at Carroll Street, where a large power plant is located, it became 70°. From here to the First Street basin the temperature rapidly became higher until 90° F. was reached. On going down the canal this soon dropped again to 70° F. and then gradually diminished, until at the entrance to the bay it became 44° F. In April the temperatures were a little higher, but varied in the same way.

The semi-liquid layer of sludge at the bottom requires merely a slight rise of temperature to cause the development of gases, which bubble up in practically the whole length of the canal. At the head end the bubbling is violent. Black solid matter arises to the surface, and discharging its burden of gas again disappears from view. The white scum at the head end is blackened and the smell is rank, becoming unbearable when the water is stirred up by the tugboats.

To sum up: The canal is an open sewer, or rather, in its present state, practically a septic tank. There is almost no current and the tide appears to exert no flushing effect whatever. Of the plants along the canal, the gas works are doubtless the chief offenders. The trouble, however, is due largely to the discharge from the city sewers, which discharging into a body of quiet water cause heavy deposits to be formed. The canal water being stagnant and devoid of oxygen, the deposits putrefy and are the seat of the nuisance. These conclusions are borne out by the chemical and bacteriological analyses.

CHEMICAL AND BACTERIOLOGICAL ANALYSES

Before taking up the regular analytical work, it was thought best to ascertain from a few preliminary samples from various portions of the canal the character of the water to be analyzed.

Two of these samples, one taken at the Union Street bridge near the head of the canal, and the other at the Ninth Street bridge near the lower end, gave interesting results. The first was strongly indicative of sewage, the other of industrial wastes. Tests were made for acidity. The first was found to be neutral to litmus, acid to phenolphthalein, and alkaline to methyl orange. The other, although neutral to litmus, was acid to both phenolphthalein and methyl orange. Both were decidedly turbid and had much matter in suspension. The behavior on evaporation on the steam bath and on ignition also deserves attention. The first blackened readily on ignition and gave off a strong sewage odor. The second on the bath gave off an acetic acid odor; on ignition the solid matter decrepitated, and the odor was at first leathery, then like fertilizer, and finally very offensive. The substance burned with great difficulty, indicating vegetable carbon. Both samples contained a large amount of chlorine and sulphates, the second, however, in much greater proportions than the first.

Pollution by the gas plants was particularly evident, both from the odor of the water and from the color and behavior of the precipitate formed on nesslerization. This, instead of being of the reddish color characteristic of ammonia, was a heavy, curdy precipitate, canary yellow in color, the reaction indicating amines.

It was decided in the regular series of analyses to make the following six tests chemically: oxygen consumed, total organic nitrogen, free ammonia, dissolved oxygen, turbidity, and chlorine. From ratios of these six in sea water and sewage an attempt has been made to determine the degree of pollution of the canal.

Method of Taking Samples. — In obtaining samples care was taken to choose representative points along the canal and to guard against accidental or abnormal conditions. The samples were taken from a rowboat at different depths and at different points in a cross-section of the canal. This was done by letting up and down a large bottle with a double perforated stopper while rowing across the canal. The contents of the bottle were then emptied into a pail and a liter bottle was filled from the mixture. This method gave a sample which was fairly representative of the cross-section of the canal from which it was taken.

As soon as the samples for the entire canal were obtained they were immediately taken to the Mount Prospect Laboratory, which was within twenty minutes' ride from the canal.

Methods of Chemical and Physical Analysis. — With the exception of the test for turbidity, the methods of chemical and physical analysis were those recommended by the Committee on Standard Methods of Water Analysis. The oxygen consumed was determined by the five-minute-boil method, the nitrogen content by the Kjeldahl Process, and the free ammonia by direct nesslerization. The turbidity was determined by means of the Jackson turbidimeter. The observation was made by pouring the sample of water into the tube until the image of the candle disappeared. The turbidity was then read from a graduation on the side of the tube. This graduation corresponded to the turbidity produced in distilled water by a certain number of parts per million of silica standard.

Methods of Bacteriological Analysis. — The media used for this work were standard media, made according to the procedure established by the Committee on Standard Methods of the American Public Health Association. The determinations were made for total count per cubic centimeter by plating on gelatin at 20° C., body temperature count on litmus lactose agar at 37° C., and tests on gas production, the latter being the only tests for *B. coli* considered necessary. In plating, two dilutions, one to 1,000 and one to 10,000, respectively, were made.

In the first series of analyses, use was made of the method of direct inoculation of 1 c.c. of the canal water into the Smith fermentation tube, but in a second series this method was abandoned in favor of Dr. Jackson's new bile media.[1]

Tests for Bacillus coli. — In the fermentation tubes 25 per cent. to 70 per cent. gas was considered indicative of the colon bacillus, and a positive record was made if the other tests were favorable, *i. e.*, if the proportion of CO_2 fell within the right limit. This limit was from 25 per cent. to 40 per cent. absorption by caustic.

FIRST SERIES OF ANALYSES

Dissolved Oxygen. — Examinations of the water for dissolved oxygen were carried on simultaneously with the sanitary inspection. About thirty samples were taken at intervals along the canal from the head end to Hamilton Avenue, and, with the few following exceptions, negative results were obtained. Four surface samples also were taken from the East River, and the results of analysis are given in the second table below.

GOWANUS CANAL

No.	Place of collection.	Temperature.	c.c. oxygen per liter.	Per cent. saturation.
1	Entrance to power house basin, 4 P.M.	80° F.	1.14	20.2
2	East pier, Third Street bridge, 4 P.M.	70° F.	0.58	9.3
3	Entrance power house basin 9 A.M. next day	90° F.	1.54	30.4
4	Just below basin	90° F.	1.05	20.7
5	Above Third Street bridge	70° F.	1.03	16.5
6	Below Third Street bridge	70° F.	1.01	16.2
7	20 feet below Third Street bridge	70° F.	0.73	11.7
8	75 feet below Third Street bridge	70° F.	0.30	4.8
9	100 feet below Third Street bridge	70° F.	0.00	0.0

EAST RIVER

No.	Place of collection.	Temperature.	c.c. oxygen per liter.	Per cent. saturation.
1	Buttermilk Channel, 200 feet from Brooklyn side	35° F.	7.50	77.4
2	Mid-stream opposite Governor's Island	30° F.	7.58	74.5
3	Return trip, same as 2	30° F.	7.95	78.0
4	Buttermilk Channel, 75 feet from Brooklyn side	34° F.	7.90	80.5

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[1] For description, see Biological Studies by the Pupils of William Thompson Sedgwick, Boston, 1906, pp. 292–299.

The other results of the first series are shown in tabulated form in Table I.

Analysis of the Sludge. — Samples of the sludge which appeared to form a semi-liquid layer on the bottom were analyzed for total solids, oxygen consumed, and total organic nitrogen Inasmuch as the method of taking samples was crude and allowed some water to mix with the sludge, the density was changed. The results are therefore expressed in ratios for comparison.

Location of sample.	Oxygen consumed: total nitrogen.	C + N: total solids.
Head of canal	16.2	1 : 1.9
150 feet below head	13.0	1 : 2.0
300 feet below head	9.8	1 : 2.2
Opposite Degraw Street	11.0	1 : 2.1
Entrance First Street basin	10.3	1 : 3.3
Entrance Fifth Street basin	7.0	1 : 3.1
Opposite Bond Street	13.0	1 : 3.5

Experiments were made on the temperature necessary to develop gases from the sludge. Ten c.c. of the various samples were diluted to about 60 c.c. and placed on ice. After standing on the ice for several hours, all the foul air possible was exhausted and replaced by fresh air. The bottles were then set back into the ice chest and allowed to remain there over night. The temperature of the ice chamber was 2° C. At this temperature no sewage odor was noticeable. The samples were then allowed to stand in the room, and their condition was noted from time to time. No. 1 became offensive at 12° C.; Nos. 2, 3, and 4 at 12.5° to 13° C. Sample No. 5 contained a quantity of tarry matter and required a temperature of 14° C. to become offensive. The samples were then slowly warmed. At 20° C. the odor was very strong. At 23° C. the stench became vile and unbearable, especially in the first three samples.

A sample of the incrusting substance on the bulwarks was also taken. On analysis this was found to be a tarry waste product of the gas works.

SECOND SERIES OF ANALYSES

The first series of analyses was made in February, 1906. The second was carried out in April. This series included a sample of

TABLE I. — SHOWING ANALYSIS OF SAMPLES TAKEN FROM THE GOWANUS CANAL, FEBRUARY 3, 1906

CHEMICAL ANALYSIS (Parts per Million)

No.	Place of collection.	Temperature.	Turbidity. (Parts per million of silica.)	Nitrogen as		Chlorine.	Oxygen consumed.	Number of bacteria per c.c., 48 hours at 20° C.	B. Coli
				Total organic nitrogen.	Free ammonia.				In 1 c.c.
1	Head of canal	. .	420	50.4	17.0	300	95.3	3,220,000	+
2	Just below Degraw Street	. .	265	44.0	17.0	1,400	64.0	1,440,000	+
3	Just below Carroll Street	. .	100	12.2	7.0	4,000	46.4	252,000	+
4	Entrance First Street basin	90° F.	105	10.4	4.4	5,700	36.8	99,000	+
5	Entrance Fifth Street basin	. .	125	8.2	6.6	5,900	43.2	171,000	+
6	Opposite Bond Street	. .	95	10.4	4.4	6,400	28.8	168,000	+
7	In Sixth Street basin	. .	160	14.7	6.1	6,200	45.6	217,000	+
8	Entrance Eighth Street basin above tartar factory	. .	100	15.9	3.3	6,700	42.4	217,000	+
9	Below Ninth Street	65° F.	90	13.9	5.3	7,000	35.2	254,000	+
10	Below Hamilton Avenue	55° F.	110	4.8	4.8	7,450	56.8	90,000	+
11	Entrance to bay	44° F.	120	13.5	5.7	7,500	102.4	69,000	+

NOTE. — Samples were taken at time of flood tide.

sewage taken from a manhole at the corner of Nevins and Butler Streets, and fifteen samples taken from different portions of the canal. The sample from the manhole was taken on Saturday morning, April 14. The depth of flow in the sewer was 6 inches. The samples from the canal were not taken until Monday morning, April 16. A heavy rain fell on Saturday night and Sunday morning, and the canal water was well stirred up.

In this series samples were analyzed both filtered and unfiltered, and the test for total solids was added. In the latter the sodium chloride present rapidly took on moisture from the air, and for that reason the tests for total and dissolved solids are rough and therefore of not much importance. The results of the second series are given in tabulated form in Table II.

Tests for putrescibility of the sewage and the degree of dilution necessary were made by the methylene blue test. This was done by adding 1 c.c. of a 0.1 per cent. solution of methylene blue to a half pint of the different dilutions of the sewage with tap water. These tests showed a dilution of one part sewage to fifteen parts water to be necessary for a stable mixture.

INTERPRETATION OF THE RESULTS

Interpretation of Figures Obtained.—The tabulated results give evidence of the amount and nature of the pollution. Tables, however, show more when they are represented graphically. Therefore to aid in the interpretation the results obtained have been plotted. The construction of the diagrams needs no explanation. The curves are striking and interesting. With the exception of those for chlorine and total and dissolved solids, they all have a general downward tendency, which shows the effect of dilution with sea water. The curves for the first series are much smoother than those for the second, because the second series of samples was taken after the canal had been stirred up by a heavy rainfall. It will be interesting to examine the curves and to account for the variations which occur.

Total Organic Nitrogen.—In the first series (Fig. 10) this curve falls rapidly until Bond Street is reached. Here it again rises, reaching a maximum opposite the Tartar Chemical Company.

In the second series (Fig. 12) there is a general decrease. The curve drops rapidly at the entrance to the First Street basin. This is

TABLE II. — SHOWING ANALYSIS OF SAMPLES TAKEN FROM THE GOWANUS CANAL, APRIL 16, 1906

CHEMICAL ANALYSIS (Parts per Million)

No.	Place of collection.	Temperature.	Turbidity (parts per million of silica).	NITROGEN AS				Total solids.	Suspended solids.	In solution.	Chlorine.	OXYGEN CONSUMED.			Number of bacteria per c.c., 48 hours at 20° C.	B. COLI		
				Organic nitrogen			Free ammonia.											
				In solution.	In suspension.	Total.						In solution.	In suspension.	Total.		In 0.1 c.c.	In 1 c.c.	In 10 c.c.
	Sewage taken from manhole, corner Nevins and Butler Streets, April 14, 1906, 9 A.M.	. .	475	51.8	19.5	71.3	36.0	1,860	1,220	640	230	116.4	48.6	165.0	3,120,000	+	+	+
1	Head of canal	77°.0 F.	380	30.5	19.3	49.8	24.0	1,160	260	900	350	42.3	33.2	75.5	—	+	+	+
2	Opposite Sackett Street	77°.0 F.	320	17.8	25.7	43.5	11.0	3,580	320	3,260	1,010	48.6	37.4	86.0	1,680,000	+	+	+
3	Below Carroll Street	99°.5 F.	1,000	8.8	22.5	31.3	4.0	11,980	480	11,500	4,600	17.6	91.7	109.3	1,280,000	+	+	+
4	Entrance First Street basin	101°.3 F.	150	9.8	1.6	11.4	3.0	10,720	1,260	9,460	4,700	16.2	9.2	25.4	1,030,000	+	+	+
5	Above Third Street	91°.4 F.	400	5.3	12.8	18.1	4.3	12,380	620	11,760	4,600	17.6	67.8	85.4	685,000	+	+	+
6	Opposite Fifth Street basin	73°.4 F.	265	24.8	12.8	37.6	4.0	10,540	2,440	8,140	4,850	14.1	32.4	46.5	670,000	+	+	+
7	Below Bond Street	. .	385	8.8	4.8	13.6	4.0	15,540	6,600	8,940	3,890	20.4	57.1	77.5	643,000	—	—	+
8	Opposite Sixth Street basin	. .	155	7.8	1.0	8.8	4.0	7,100	380	6,720	3,100	16.9	7.1	24.0	360,000	+	—	+
9	Above Seventh Street basin	55°.4 F.	160	8.3	2.6	10.9	3.5	11,300	1,820	9,480	4,100	12.7	8.5	21.2	228,000	+	+	+
10	Below Seventh Street basin	. .	175	19.9	6.4	26.3	2.5	9,500	180	9,320	4,200	12.7	7.0	19.7	223,000	+	+	+
11	Below Ninth Street	. .	290[1]	6.8	3.2	10.0	6.0	9,480	780	8,700	4,480	14.8	4.9	19.7	219,000	+	+	+
12	Above Eleventh Street basin	. .	90	7.1	3.2	10.3	2.5	21,040	1,660	19,380	4,050	16.2	9.2	25.4	—	+	+	+
13	Above Hamilton Avenue (near sewer outlet)	. .	85	0.7	0.4	1.1	8.5	17,720	540	17,180	5,100	6.9	3.0	9.9	—	+	+	+
14	Below Hamilton Avenue (opposite sewer outlet)	51°.8 F.	80	6.0	4.8	10.8	2.0	24,320	12,360	11,960	5,200	13.3	5.0	18.3	296,000	+	+	+
15	Entrance to bay	50°.0 F.	70	. .	. .	9.3	3.5	19,900	6,360	13,540	6,950	7.1	7.7	14.8	335,000	+	+	+

NOTE. — Samples taken on a rising tide.

[1] Milky.

due to the large amount of clean water discharged from the power house. At Third Street the curve rises to what would be a point on the normal dilution curve. Opposite the Fifth Street basin there is a rapid rise, which is due to a stirring up of the water at that point by tugs at the time that the sample was taken. The curve then again drops rapidly, but not to what would be a point on the normal dilution curve. The Bond Street sewer enters here. There is then a gradual drop until we arrive at the Tartar Chemical Company, where there is a sudden increase. Above Hamilton Avenue bridge there is another quick drop. A glance at some of the other curves shows that this drop is general. On the other side of the bridge, however, the curve rises again.

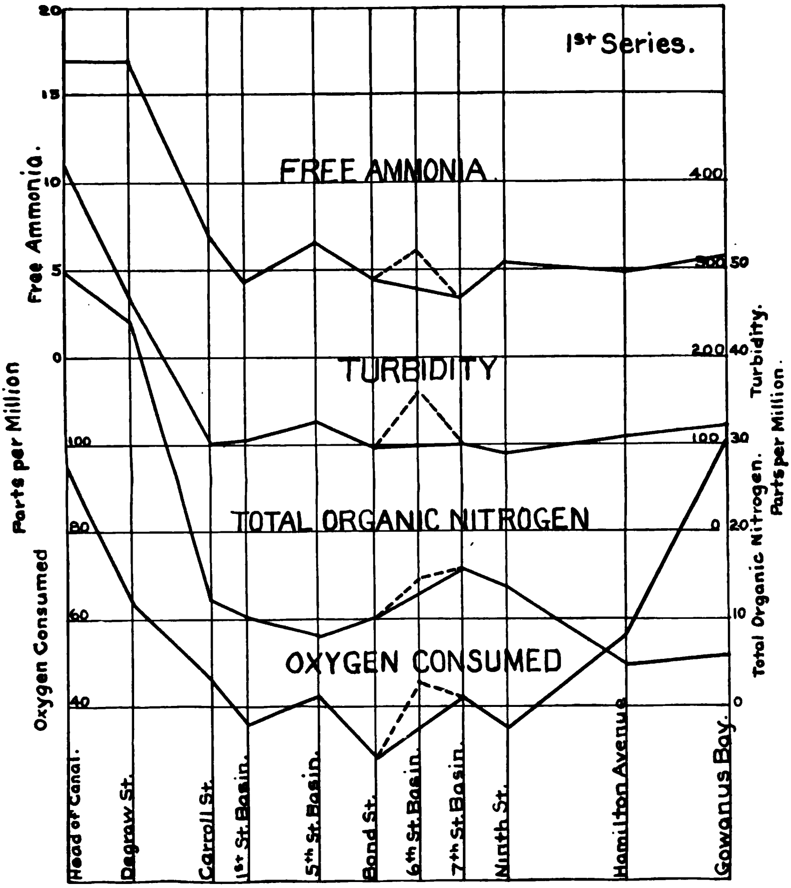

FIG. 10

A sewer enters here. There is then a slow, gradual decrease, indicating dilution with sea water.

The curves for suspended and dissolved organic nitrogen are similar to that for the total organic nitrogen, and no special comment on them is necessary.

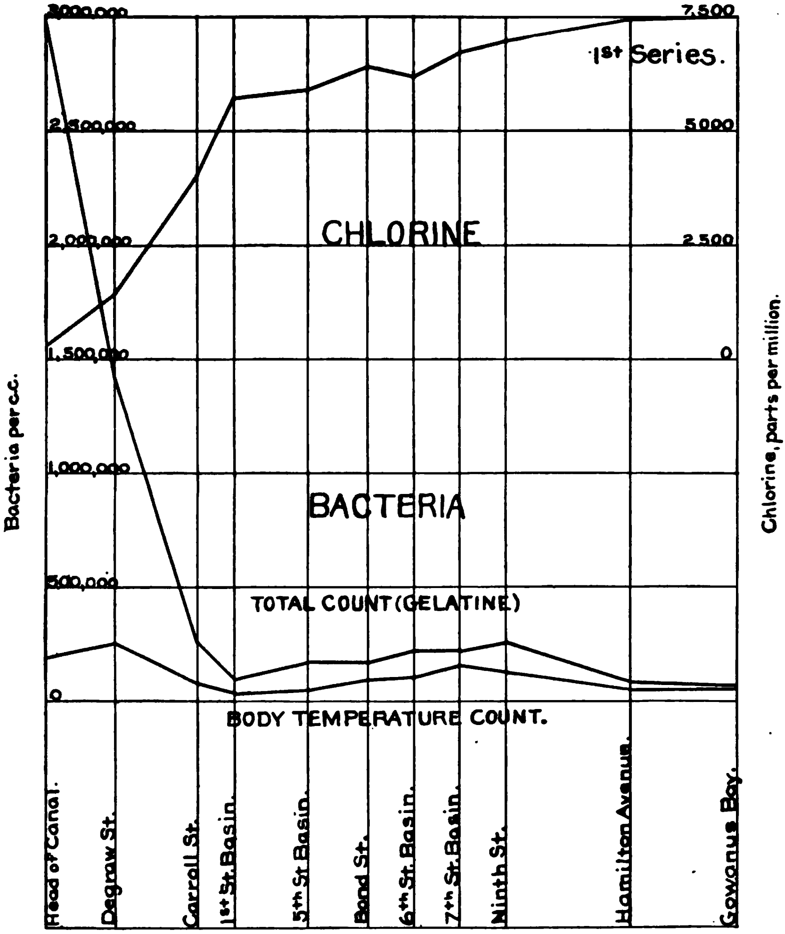

FIG. 11

Oxygen Consumed.—In the first series (Fig. 10) this curve falls off rapidly until after Bond Street is passed. Opposite the Fifth Street basin there is an increase, probably due to coal dust. The most conspicuous part of the curve, however, is the steady and rapid increase after the starch factory at Ninth Street is passed.

In the second series (Fig. 13) there is an increase at the start, with a quick rise at Carroll Street. A glance at the turbidity curve will show that this rise is due to the water having been stirred up. There is a quick drop at the First Street basin and a quick rise again at Third Street. The turbidity also is high at this point. The apparent drop at the Fifth Street basin was unexpected, since the nitrogen is high at that point. A further study of the diagrams, however, will show that the oxygen consumed is also absolutely very high.

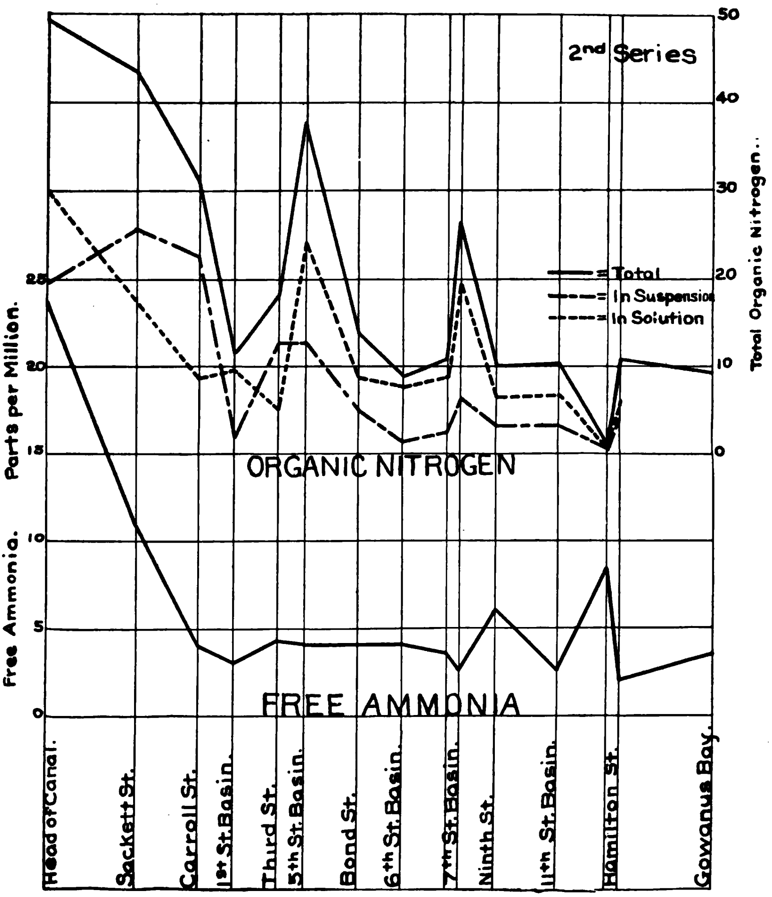

FIG. 12

After passing Bond Street the curve has a downward tendency, with only a slight rise beyond Ninth Street. This is significant. The samples were taken on a Monday morning, and there was no pollution then by the starch factory.′ Most of the material which had been discharged on Saturday night was flushed out by the heavy flow of storm water on Saturday night and Sunday.

The same drop just above the Hamilton Avenue bridge already mentioned in the discussion of the organic nitrogen curve is conspicuous here. Below Hamilton Avenue the curve rises again and then decreases gradually.

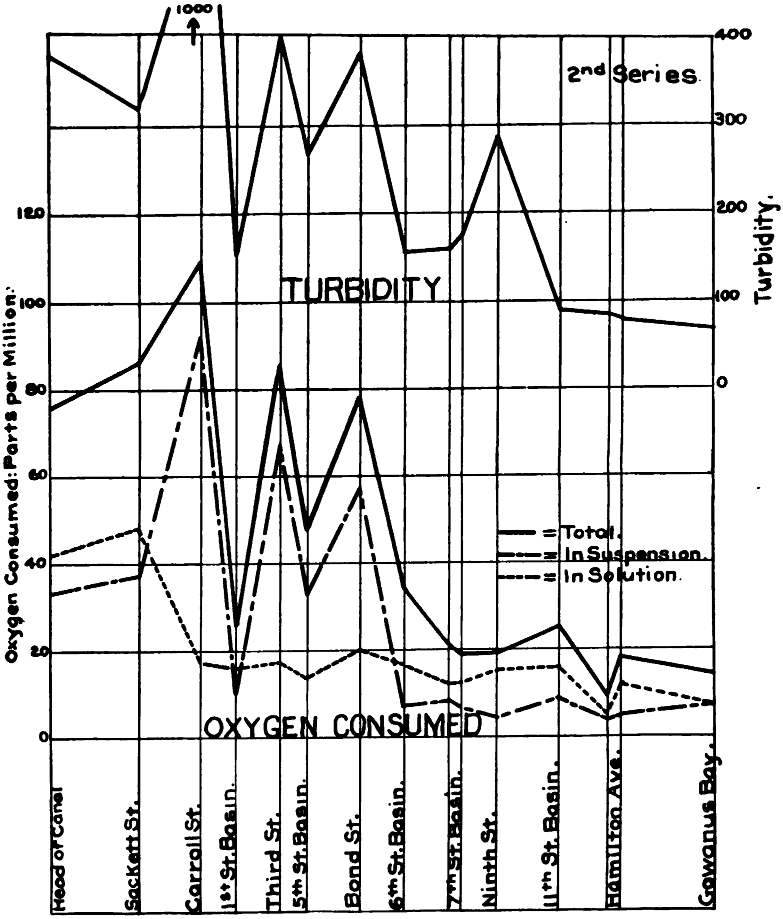

FIG. 13

Turbidity.— In both series of analyses (Figs. 10 and 13) this curve seems to vary with the dilution and shows that sedimentation has taken place all the way down, being interrupted occasionally by the stirring up of the water. The curves for turbidity are strikingly similar to those for organic nitrogen and for oxygen consumed.

The remaining curves simply reënforce points brought out in the curves already discussed and require no especial explanation. We are, therefore, ready to consider the various curves simultaneously. Sample No. 1 shows at once that we have much accumulated solid matter which is constantly stirred up. The nitrogen is very high. This means that there is an additional supply of organic matter there, which, being constantly stirred up, keeps in circulation, but is never carried out. This

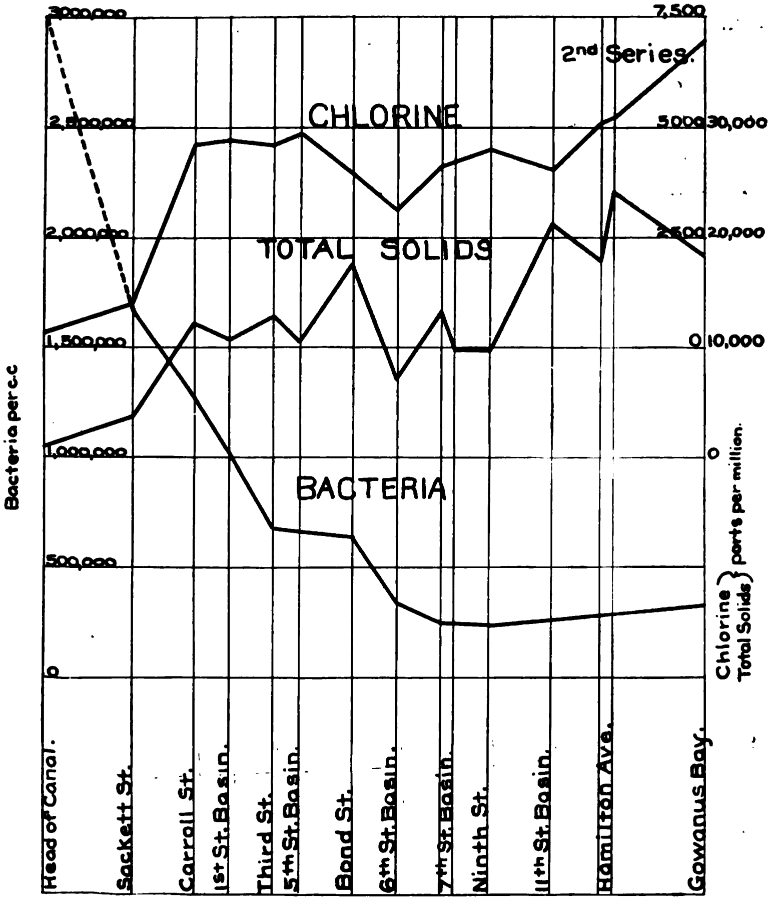

FIG. 14

effect is not lost all the way down the canal. The fact that the chlorine is above the normal — twice what it ought to be — shows a mixture of sea water with the sewage. In the first five samples the ratio of dissolved nitrogen to total nitrogen gives good evidence of septic action. Since organic nitrogen is converted into free ammonia, there are two changes noticeable: the ratio of free ammonia to total organic nitrogen and the ratio of oxygen consumed to total organic nitrogen becomes greater. Both carbon and nitrogen are going down, but the nitrogen goes down much faster.

From a bacteriological standpoint, the low count at body temperature as compared with the high total count in water from the head of the canal is interesting. It indicates that septic action is taking place and corroborates the evidence mentioned in the last paragraph.

The total number of bacteria falls off very rapidly on going down the canal, reaching in the first series of analyses (Fig. 11) a minimum opposite the First Street basin. In the second series (Fig. 14) this minimum is not reached until the Seventh Street basin is reached, showing the flushing effect of the storm water. A glance at the curves for chlorine shows that this rapid decrease in the total bacteria count is due to dilution.

Below the First Street basin the number of bacteria does not increase materially, thus substantiating the evidence that most of the pollution below this point is due to industrial wastes.

The discharge of the Bond Street sewer seems to increase the oxygen consumed, but not the nitrogen. The bacteria go down, and this sewage seems to be an antiseptic, non-nitrogenous substance, in appearance quite similar to gas plant wastes.

Lateral Basins. — In the first series, to ascertain how the water in the basins compared with that in the main part of the canal, a sample was taken from one of these. This is represented in the curve (Fig. 10) by dotted lines. The result is significant. A glance at the curves shows that free ammonia, oxygen consumed, total organic nitrogen, turbidity, and the total bacteria count are higher than in the adjacent portion of the main canal, while the chlorine and the body temperature count are lower. This is characteristic of a dead end. The depression in the chlorine curve shows that the tide exerts no flushing effect, and the low body temperature count shows that the water in the basin is stagnant.

Variations between the Two Series. — The first series of analyses was carried on at a time when there was no rain. The second series of samples was taken after the run off from a heavy rainfall had stirred up the contents of the canal. On comparing the two sets of curves, the reader will see that in general they cross one another several times, that the curves of the second series are very ragged, plainly giving evidence of a general stirring up. At the uppermost point of the canal, however, the second series shows less pollution than the first. The curves soon cross, however, and in general the first series of curves is lower than the second. This is due to the large volume of storm water which had pushed the sewage at the head end farther down. The turbidity curve for the second series is entirely above that for the first series.

Difference in Character of Pollution in Various Parts of the Canal.—The upper part of the canal is badly polluted by sewage. At the lower end the pollution is largely industrial wastes mixed with more or less sewage.

As a rule, the amount of nitrogen present varies directly with the amount of sewage. The other constituents of sewage vary with the nitrogen. Therefore when the nitrogen is greatly increased without a corresponding increase in the other sewage substances it is an indication of industrial wastes. This is exactly what happens in that portion of the canal opposite the Tartar Chemical Company. On talking with one of their employees, we learned that crude argol is digested with sulphuric acid, and that the waste product is an acid sludge running high in sulphates and nitrogen.

In the first series, below Ninth Street the oxygen consumed curve went up rapidly. In the second series the curve had a downward tendency. The starch factory, not running on Sunday, had no waste to discharge at that time. The abnormal values for the oxygen consumed are probably due to gluten in the wastes discharged by the starch factory.

Another interesting point, characteristic of both series of curves, is the sudden drop in most of the curves just above Hamilton Avenue. It is significant that not only the organic nitrogen, oxygen consumed, turbidity, and total solids, but the bacteria also go down. This looks like precipitation. The curves for ammonia and chlorine, on the other hand, show a slight increase. Immediately above this point is a coal gas plant, which evidently uses lime to recover its ammonia. The waste from the Tartar Chemical Company, which is carried along by the tide, comes into contact with the gas plant waste, and calcium sulphate is probably precipitated, carrying down with it nearly all the other suspended matter.

The rapid decrease in bacteria below Bond Street gives evidence of antiseptic action. A glance at the diagrams will show that, although the nitrogen and carbon go up at that point, the ammonia remains the same, and the bacteria count goes down and stays down. The fact that the ratio of carbon to nitrogen is greatly increased shows that the pollution from the Bond Street sewer is largely of a carbonaceous nature.

Although taken at different times, and thus representing different conditions, there is no essential difference in the results obtained from the two series. The second series simply reënforces the first and justifies drawing the following conclusions:

The canal is highly polluted with house drainage and industrial wastes. The city sewers are the chief source of the trouble. The organic animal matters contained in the sewage are more easily susceptible to putrefactive influences than is the vegetable matter in the industrial wastes. The tide exerts very little flushing effect in the main body of the canal, and practically none whatever in the dead ends or basins.

SUMMARY OF EXISTING CONDITIONS

The table below will show the immense pollution of the canal. The figures for sea water were taken from the Report of the Committee on the Charles River Dam. The figures for Boston tap were taken from the Massachusetts Board of Health Report for 1904. Those for harbor water are the average of the accompanying table, compiled from analyses made by Dr. Jackson for the New York Bay Pollution Commission.

Sample.	Free NH_3.	Organic nitrogen.	Oxygen consumed.
From head of canal	24.0	50.1	85.4
Sea water	0.012	0.16	. .
Boston tap	0.015	0.29	3.9
Harbor water	0.534	1.28	. .

The figures speak for themselves. The pollution of the canal is almost fifty times that of the harbor.

CHEMICAL ANALYSIS (Parts per Million)

No.	Date of collection.	Place of collection.	Temperature.	Turbidity (parts per million of silica).	Tide.	Nitrogen as: Albuminoid ammonia.	Nitrogen as: Free ammonia.	Nitrogen as: Nitrites.	Chlorine.	Dissolved oxygen; c.c. per liter.	Number of bacteria per c.c., 48 hours at 20° C.	B. Coli: In 0.1 c.c.	B. Coli: In 1 c.c.	B. Coli: In 10 c.c.
	April 1, 1905, A.M.													
1	9.55	Off Battery (bottom)	—	7	Flood	0.27	0.31	. .	11,800	8.62	4,280	+	+	+
2	10.00	Off Battery (surface)	—	10	Flood	0.27	0.32	. .	6,100	8.84	6,250	+	+	+
3	10.05	Fast River off Pier No. 15	. .	10	Flood	—	—	. .	4,800	. .	4,410	+	+	+
4	10.10	Under Manhattan Bridge	—	8	Flood	0.32	0.49	. .	9,600	. .	8,460	+	+	+
	Jan. 30, P.M.													
9	12.35	Off Battery and Governor's Island (midstream, 5 feet from surface)	37°.0 F.	45	Flood	0.78	0.97	0.012	7,600	8.50	1,510	+	+	+
8	12.30	Off Battery and Governor's Island (midstream, 40 feet from surface)	37°.0 F.	30	Flood	0.73	0.84	0.015	11,600	—	920	+	+	+
7	12.20	Off Battery and Governor's Island (midstream, 80 feet from surface)	37°.0 F.	35	Flood	0.73	0.75	0.012	12,700	—	760	+	+	+
12	3.15	Off Battery and Governor's Island (midstream, 5 feet from surface)	. .	18	Ebb	0.73	1.11	0.013	9,100	8.60	1,200	+	+	+
11	3.10	Off Battery and Governor's Island (midstream, 40 feet from surface)	. .	20	Ebb	0.67	0.70	0.012	13,100	—	740	+	+	+
10	3.00	Off Battery and Governor's Island (midstream, 80 feet from surface)	. .	25	Ebb	0.71	0.72	0.011	13,200	—	540	+	+	+
		Series No. 6												
27	3.38	Off Battery	33°.0 F.	6	. .	0.28	0.36	. .	8,300	. .	7,280	+	+	+
28	3.45	Off Pier No. 6, East River	33°.5 F.	—	. .	—	—	. .	8,400	. .	14,100	+	+	+
29	3.55	Off Pier No. 13, East River	33°.5 F.	10	. .	0.24	0.41	. .	8,600	. .	18,400	+	+	+
30	3.58	Off Pier No. 20, East River	33°.5 F.	5	. .	0.21	0.37	. .	8,900	. .	12,600	+	+	+
31	4.00	Off Pier No. 28, East River	33°.5 F.	7	. .	0.40	0.52	. .	8,400	6.98	15,300	+	+	+
32	4.05	Off Pier No. 23, East River (Brooklyn)	33°.5 F.	—	. .	—	—	. .	8,600	. .	4,300	0	0	+
33	4.15	Off Atlantic Docks, Buttermilk Channel	33°.5 F.	8	. .	0.25	0.40	. .	8,600	6.54	10,400	+	+	+
35	4.25	Gowanus Bay	. .	7	. .	0.35	0.74	. .	8,600	5.63	8,500	+	+	+
[illegible]	[illegible]	[illegible]		10		1.11	7.00	. .	6,800	. .	270,000	+	+	+

Absolute Values Compared with Sewage. — Below is given a table comparing the canal water with several well-known sewages.

Place.	Date.	Free NH_3.	Organic Nitrogen.		Chlorine.	Oxygen consumed.	Bacteria per c.c.
			Total.	Solution.			
Brooklyn	April 14, 1906	36.0	71.3	51.8	230.0	165.0	3,120,000
Boston	Average	19.9	23.0	10.5	1,300.0	45.0	3,000,000
Lawrence	Maximum, 1904	71.8	39.2	20.6	163.9	65.4	3,020,000
Lawrence	Minimum, 1904	41.6	12.1	5.4	82.7	38.4	1,440,000
Lawrence	Average, 1904	51.5	18.3	8.7	123.1	48.6	1,930,000
Andover	June, 1902	103.0	51.4	20.0	678.0	107.7	3,680,000
Andover	Average, 1902	74.6	35.8	17.0	164.7	76.7	3,750,000
Head of canal	Mean	24.0	50.1	30.5	325.0	85.4	3,100,000
Opposite Fifth Street basin	Mean	7.5	37.6	24.8	4,850.0	46.5	670,000
Below Hamilton Avenue	Mean	3.5	7.8	4.5	6,325.0	18.3	200,000

From the above table it is evident that the water at the head of the canal is about two-thirds as strong as Brooklyn sewage. It is more than twice as strong as Boston sewage; its strength is three times that of Lawrence sewage and about equal to that of Andover, which is one of the strongest in Massachusetts.

The sample taken opposite the Fifth Street basin corresponds to the strongest Lawrence sewage in 1904, and to the average Andover sewage for 1902.

At Hamilton Avenue the water contains about one-tenth of Brooklyn sewage, and is about one-half the strength of the minimum Lawrence sewage in 1904.

RECOMMENDATIONS, WITH CALCULATION OF THE AMOUNT OF WATER TO BE PUMPED

Recommendations. — The Gowanus Canal is in a very poor sanitary condition, and measures should be taken to abate this nuisance as soon as possible. In the study from which this abstract is taken, the methods of dealing with this problem came under two heads, those which involve some method of flushing the canal and those involving a sewerage system for the locality. These were taken up and considered in detail by the writer's colleague in the investigation — Mr. Norman P. Gerhard, now assistant engineer, Board of Water Supply, City of New York.

It is not the purpose of this abstract to suggest a remedy, since the problem has already received the attention of the engineers of the Borough of Brooklyn and a flushing tunnel from the East River to the head of the Gowanus Canal is now under construction. The writer will therefore confine himself, as he did in the original thesis, to a calculation of the amount of water to be pumped under various methods of flushing the canal.

Calculations were made in two cases. In the first it was assumed that flushing alone would be considered and enough water pumped in to render the sewage matter innocuous and to create a current strong enough to prevent it from settling out. In the second case it was assumed that intercepting sewers would be built and the district sewered, enough water being pumped to cleanse the canal in a reasonable length of time, and thereafter create a small current sufficient to prevent it from becoming stagnant.

Both methods require that the present sludge deposits should be removed by dredging. A tremendous quantity of water would be required to give sufficient scouring velocity to remove the sludge. Even so, the present nuisance at the head of the Gowanus Canal would only be transferred to its branch dead ends and into Gowanus Bay. The power of New York Harbor to dispose of the sewage that comes into it is already being questioned. The Harbor Pollution Commission found that the tide has little effect in eliminating the pollution of the bay, and that the water seems incapable of renewing its supply of oxygen. It is evident then that it would be unwise to pollute the harbor still more by flushing into it the sludge which has accumulated in the Gowanus Canal.

Calculation of the Amount of Water to be Pumped. — We have, therefore, to consider for calculation two possibilities, the daily dilution of the total amount of sewage discharged into the Gowanus Canal, and the remedying of its present unsanitary condition in case an intercepting sewer should be built. The object of these calculations is to compute the required dilution from figures obtained by chemical analyses. Before proceeding with these calculations it is necessary, however, to determine first the proportion of sewage at present in the canal.

Sewage Density. — This may be defined as the proportion of sewage per unit volume. The canal water can be considered as a mixture of three separate liquids: sewage, terrestrial (*i.e.*, surface + ground) water, and harbor water. The object of these calculations is to obtain absolute values for each of these three. In making these calculations, use has been made of the usual method of determining by the chlorine content in a mixture of two such liquids the proportion of each. This gave two independent equations. A third equation was obtained by means of the nitrogen values. The method of attack was as follows:

Consider a section in the canal of unit dimensions. Let

x = portion of sewage;
y = portion of terrestrial water;
z = portion of harbor water;
C = total chlorine;
N = total nitrogen;
c_1 = chlorine in sewage;
c_2 = chlorine in terrestrial water;
c_3 = chlorine in harbor water;
n_1 = nitrogen in sewage;
n_2 = nitrogen in terrestrial water;
n_3 = nitrogen in harbor water.

We then have the equations:

$$x + y + z = 1. \tag{1}$$

$$xc_1 + yc_2 + zc_3 = C. \tag{2}$$

$$xn_1 + yn_2 + zn_3 = N. \tag{3}$$

To solve we must find or assume values for the constants. The pollution of the canal is so great that the amount of nitrogen in terrestrial water when compared with it is practically zero. Considering the proximity to the sea, we may assume 10 as an average value of the chlorine content of this water.

From the table given above, showing the analyses made by Dr. Jackson for the New York Bay Pollution Commission, it appears that average figures for the nitrogen and chlorine content of harbor water may be assumed at 1 and 8,600, respectively.

Considering the particular problem on hand, we therefore have the following constants:

$$c_1 = 230;\ c_2 = 10;\ c_3 = 8{,}600;$$

$$n_1 = 107;\ n_2 = 0;\ n_3 = 1.$$

Substituting these values in the above equations, the two following tables, showing the proportion of sewage, terrestrial water, and harbor water at different sections in the canal, have been computed:

FIRST SERIES

No. of sample.	C.	N.	PROPORTION OF Sewage.	PROPORTION OF Terrestrial water.	PROPORTION OF Harbor water.
1	300	67.4	.63	.36	.01
2	1,400	61.0	.57	.42	.01
3	4,000	19.2	.18	.35	.47
4	5,700	14.8	.13	.19	.68
5	5,900	14.8	.13	.14	.73
6	6,400	14.8	.13	.08	.79
7	6,200	20.9	.19	.03	.78
8	6,700	19.2	.17	.03	.80
9	7,000	19.2	.17	.03	.80
10	7,450	9.6	.08	.09	.83
11	7,500	19.2	.17	.03	.80

SECOND SERIES

No. of sample.	C.	N.	PROPORTION OF Sewage.	PROPORTION OF Terrestrial water.	PROPORTION OF Harbor water.
1	350	73.8	.69	.31	.01
2	1,010	54.5	.51	.35	.14
3	4,600	35.3	.32	.05	.63
4	4,700	14.4	.13	.33	.54
5	4,600	22.4	.13	.29	.58
6	4,850	41.6	.38	.05	.57
7	3,890	17.6	.16	.36	.48
8	3,100	12.8	.12	.51	.37
9	4,100	14.4	.13	.38	.49
10	4,200	28.8	.26	.24	.50
11	4,480	16.0	.15	.33	.52
12	4,050	12.8	.12	.42	.46
13	5,100	9.6	.08	.34	.58
14	5,200	12.8	.12	.28	.60
15	6,950	12.8	.11	.10	.79

Calculation of Quantity of Water to be Pumped.—One condition of the degree of dilution required to make sewage inoffensive is that the diluting water shall have a sufficient supply of free oxygen. The experiments made on Brooklyn sewage for putrescibility showed the dilution of 1 : 15 to be necessary.

The sewage discharged into the canal daily is estimated to be 793,000 cubic feet. The amount of water, therefore, to make this innocuous is 793,000 × 15 = 11,895,000 cubic feet per day. Allowing a factor of safety of 2, there would be required 23,800,000 cubic feet per day.

Supposing no sewage is allowed to enter the canal and its contents are to be flushed out in thirty days, we can calculate the necessary quantity of water as follows:

The average sewage density of the canal, as computed in the above tables, is 0.25. Therefore $x = \frac{10{,}000{,}000\ (0.25)\ (15)}{30} = 1{,}250{,}000$ cubic feet per day.

The amount of water to be pumped was also calculated by a method based on the amount of oxygen available from East River water and the average amount of oxygen consumed by water in the canal. Although there is no evidence that sewage requires oxygen equivalent to its oxygen consumed value to oxidize it under natural conditions, this calculation is interesting in that the two methods of calculation used gave practically the same result. For this reason the writer thought this calculation from chemical data might be of general interest, and has included it in this report.

This calculation was based on the assumption that the volume of the canal water and the amount of oxygen consumed by it bears some relation to the amount of water to be pumped and the free or dissolved oxygen in it. We can express this relation algebraically as

$$xO_d = KSO_c$$

where x = quantity of East River water to be pumped in cubic feet per day.

O_d = amount of dissolved oxygen in parts per million in the water to be pumped.

S = amount of sewage to be oxidized in cubic feet per day.

O_c = oxygen consumed by S in parts per million.

K = ratio of amount of dissolved oxygen in flushing water to amount required to oxidize the organic matter.

If O_d is all to be used up, K becomes unity, and the quantity to be pumped is $x = \frac{SO}{O_d}$.

It appears from analyses made of East River that 7.5 c.c. per liter is a fair average value for O_d.

Weight of liter O = 1.429 grams.
Weight of 1.0 c.c. O = 0.00143 gram.
Weight of 7.5 c.c. O = 0.0107 gram.

Therefore $O_d = 10.7$ parts per million and $x = \frac{SO}{10.7}$.

We will compute first the amount of water needed to render innocuous the sewage discharged into the canal. The total sewage discharged into the canal was estimated at 793,000 cubic feet per day. $O_c = 165$ parts per million. Therefore $x = \frac{793{,}000 \times 165}{10.7} = 12{,}200{,}000$ cubic feet per day.

If we allow a factor of safety of 2 to cover future increase of sewage flow, x would equal $12{,}200{,}000 \times 2 = 24{,}400{,}000$ cubic feet per day.

The amount of water needed for flushing the canal, supposing no more sewage is allowed to enter and thirty days are allowed for flushing, was computed as follows. The volume of the canal water is 10,000,000 cubic feet. S in our formula would then be $\frac{10{,}000{,}000}{30} = 333{,}330$ cubic feet per day. The average value for O_c is 46.1. Then

$$x = \frac{333{,}330 \times 46.1}{10.7} = 1{,}440{,}000 \text{ cubic feet per day.}$$

Summing up these calculations, it appears that if sewage is allowed to continue discharging into the canal perhaps 25,000,000 cubic feet of water will have to be pumped daily to dilute the canal water sufficiently to render it innocuous. If the district is to be sewered, 1,500,000 cubic feet per day will be necessary.

SUMMARY AND CONCLUSIONS

The Gowanus Canal in its present condition is unsanitary and a nuisance. Sewage enters the canal and stays there. The heavier particles settle out at once, forming banks in front of the outlets of the sewers. The light, flocculent matter moves up and down with the tide and is gradually deposited, silting up all portions of the canal